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THE DEVELOPMENT OF TRUNK WIDTH AND THE TRUNK WIDTH INDEX

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I. STATEMENT OF THE PROBLEM

THE trunk of a child, projected on the frontal plane, has a roughly rectangular form. Strictly, the form is more nearly that of a trapezoid; in which the relation between the shoulder breadth and the cristal breadth is called the trunk-breadth index.

Our problems are: What is the size of the trunk-breadth index in man; how does it vary; what are its ontogenetic and phylogenetic histories?

II. METHOD AND MATERIAL

The trunk-breadth index (acromio-cristal index; Rumpfbreiten-index) is defined by Martin ('28, p. 174) as the maximum breadth between the crests of the ilia (Martin's No. 40) × 100 divided by breadth between the acromion processes (No. 35). That is, shoulder width being the unit, the cristal width is expressed in terms of it.

Since values obtained depend on technique employed, the latter must be noted in some detail. In general, Martin's ('28) directions were followed.

a. Bi-acromial width. Straight line distance between the lateral tangents to the two acromions; shoulders at rest but not slumped forward. The acromion

is determined by palpation, frequently aided by following the scapular spine to its lateral end.

b. Intercristal width. The maximum horizontal distance between the outer lateral margins of the brim of the pelvis. The bars of the anthropometer merely rested on the skin at this pair of points. It is impracticable to measure to the bone, especially in fat people. Usually the diameter is that between the tubercules of the ilium, though these are not prominent in young children.

Relative widths are computed with maximum stature as a denominator. Suprasternale height, sitting, is also sometimes used as a unit. This suprasternale is the greatest altitude of the manubrium; sometimes lying far back toward the oesophagus.

The data were obtained by measurements repeated year after year on the same children. These were in part at the Orphan Asylum of Brooklyn (BOA), in part at Letchworth Village (LVD). Acknowledgment is gratefully made of the assistance of the officers of these institutions, particularly of Dr. C. S. Little, Superintendent of Letchworth, and of Drs. E. W. Martz and H. W. Potter, Clinical Directors at Letchworth.

III. THE GROWTH OF THE SHOULDER WIDTH (BI-ACROMIAL WIDTH)

1. *Absolute Measurements*

a. Mass Statistics

A smoothed average curve of growth of shoulder width based on 141 measurements of BOA Nordic boys from 6 to 16 years, with additional data from LVD boys after 15 years, is shown in Fig. 1, continuous line. The means of the series run from 25.2±0.5 cm. at 6 years to 35.5±0.7 cm. at 16 years, an average increase of about 1 cm. per year. The standard deviations are somewhat variable, being 1.9 cm. from 6 to 10 years; 1.6 cm. from 11 to 13 years; 2.7±.4 cm. at 15 years; 2.1 at 16 years. The high standard deviation at 15 years indicates that this is the central age of a great increase in shoulder width in boys, but that the actual age of the spurt may vary a year or more from this center. This mean developmental curve of bi-acromial width shows a nearly straight-line increase from 7 to 14 years and then an increasingly rapid rise from 14 to 17 years. After this the rate of increase (as determined from other data) diminishes, becoming nearly stationary at about 20 years with a mean width of 42 cm. or more.

Sexual. The results obtained by measuring Nordic females of the BOA series are plotted in Fig. 1, broken line. At 6 years the mean width is 24.5±0.4 cm. It increases to 34.5±0.3 cm. at 15 years, an average increase of slightly more than 1 cm. per year. The standard deviation reached a maximum of 2.3±0.2 cm. at 12 years.

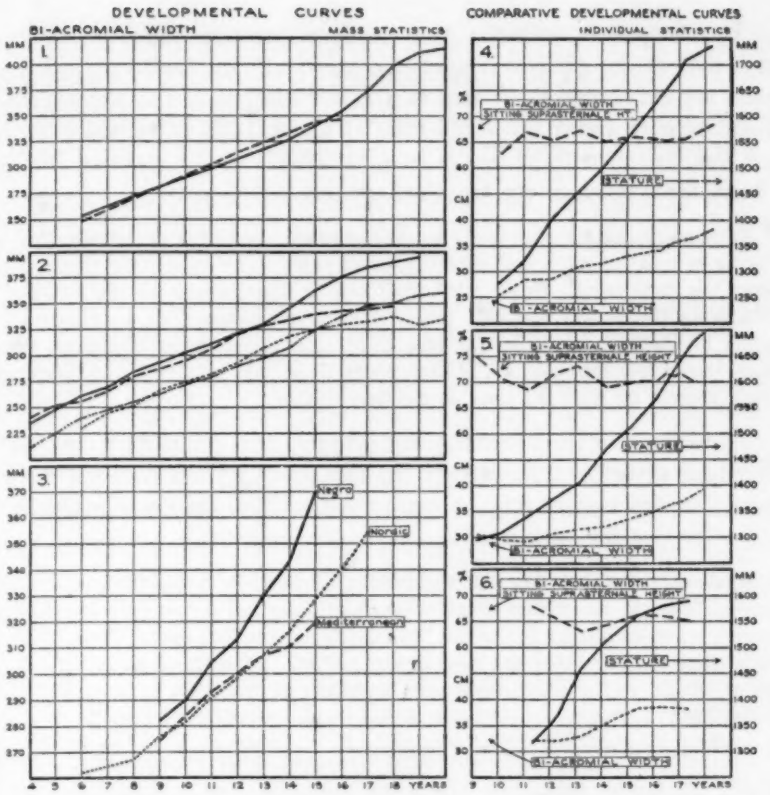


FIG. 1. DEVELOPMENTAL CURVES OF ABSOLUTE BI-ACROMIAL WIDTH
Mass statistics, both sexes. 6-15 yrs. BOA. U. S. and mixed (Nordic) smoothed. 15-20 yrs. BOA and LVD Nordic. ♂ ————. ♀ — — —.

FIG. 2. DEVELOPMENTAL CURVES OF ABSOLUTE BI-ACROMIAL WIDTH
Mass statistics, both sexes. Upper two curves, Private School children, U. S. based on Gray and Ayres. '31. ♂ ————. ♀ — — —. Lower two curves, Russian Jews, based on Weissenberg. '11. ♂ ——— . . . ——— . . . ———. ♀ --------.

FIG. 3. COMPARISON OF DIFFERENT RACES IN DEVELOPMENTAL CURVES OF ABSOLUTE BI-ACROMIAL WIDTH
Mass statistics, male, LVD. Negro ————; Nordic (slightly smoothed) -----; Mediterranean (slightly smoothed) — — —.

FIG. 4. COMPARATIVE DEVELOPMENTAL CURVES OF H. M., LVD No. 43
Above; bi-acromial width ÷ sitting suprasternal height. Below, bi-acromial width, linear type. Middle, stature (scale to right).

FIG. 5. COMPARATIVE DEVELOPMENTAL CURVES, INDIVIDUAL, OF H. F., LVD No. 20
Above, bi-acromial width ÷ sitting suprasternal height. Below, bi-acromial width (concave type). Across middle, stature (scale to right).

FIG. 6. COMPARATIVE DEVELOPMENTAL CURVES, INDIVIDUAL, OF F. B., MULATTO, LVD No. 48
Above, bi-acromial width ÷ sitting suprasternal height. Below, bi-acromial width (concave-convex type). Middle, stature (scale to right).

In comparison with the average developmental shoulder width of boys that of the girls at 6 years averages 0.7 cm. narrower and at 12 years 0.5 cm. broader. There is a I. decussation of the sex curves at about 9 years and a II. decussation at about 15⅓ years, since at that age shoulder growth slows up in girls while rapidly spurting in boys. The interval between the two decussations is 6⅓ years.

Such a decussation was found by Weissenberg, (see Fig. 2, below) also, occurring first at 8.4 years and, secondly, at 15 years. Our Mongoloid dwarf series shows the same thing. Saller ('33) finds similar decussations for the Probstei of Plön at 12 (better 11) and 16½ years. Niggli-Hürlimann ('30, p. 27) shows an excess of shoulder-width in the male child, diminishing from 5 months to 6½ years (when her series ends). Other series show that at 7 years the girls have nearly caught up with the boys in shoulder width.

It seems fair to conclude, accordingly, that in children of north European descent on the average the boys up to 7 years have the broader shoulders, from about 9 to 15 years the girls have the broader shoulders and after that the boys again.

It should be stated that the decussation of the sex curves does not always appear. Thus in the private school children of Gray and Ayres (31) the girls are from 6 years on always below the boys in shoulder width except from 12 to 13 years when the two sexes are alike in this respect. (Fig. 2, above). This is the age at which, in the BOA series, the shoulders of the girls most exceed those of the boys.

To summarize: The bi-acromial width of boys exceeds that of girls except during a period of the girls' juvenility and adolescence when conditions are reversed.

Social. On the average, in our series the BOA boys of U. S. origin have the broadest shoulders, the LVD boys come next; being, on the average, about 1 cm. narrower between 10 and 15 years and 2 cm. at age 16. The Idiot series gives still narrower shoulders, age 12 to 17 years. The Mongoloid dwarfs are about as broad-shouldered as the Idiot boys at 14 to 17 years and have apparently much narrower shoulders at below 14 years of age. At age 13 the average bi-acromial widths of the four series are respectively: 31.6, 30.5, 30.1 and 29.0 cm.

Racial. Fig. 3 gives the comparative average curves of development of bi-acromial width in LVD males for Nordic, Mediterranean and American Negro stocks. While the Nordic and Mediterranean stocks show no great difference in the growth of their shoulder width

until 13 years, after which the Nordics exceed, the Negroes' shoulders are broader at all stages of development from 9 to 15 years.

Weissenberg's Russian Jew children have much narrower shoulders than the Nordics of our series, but conditions for child development in Russia and at Letchworth Village are so different that the curves do not certainly reveal the genetic differences between racial stocks. The average adult shoulder width of athletes at Cologne is given by Bach ('27, p. 6) as 38.3±0.1.

In the measurement of United States troops at demobilization, 1919, (Davenport and Love, '21, p. 207) the colored men were found to have broader shoulders (42.9 cm.) than whites (41.8 cm.) (measured between deltoids of right and left arms). However, in the Jamaican studies of Davenport and Steggerda, ('29, p. 56) no significant difference was found between Negro and white males; but the female blacks had significantly broader shoulders than the female whites. The male West African Negroes (Werninger, '27, p. 120) have the large average bi-acromial width of 37.5 cm. The Australian aborigines have extremely narrow shoulders; deltoid width of males 39.1; of females 36.3 (Davenport, '25, p. 78).

To summarize: The European stocks have narrower shoulders than the American Negro. Of the Europeans the Nordic boys at 14 years, and older, probably have broader shoulders than those of Mediterranean origin.

b. Individual Statistics

The individual curves of absolute growth of acromial width fall roughly into three types: (1) the straight, (2) the concave above, or shallow U-shaped, and (3) the concave-convex. Of course there are plenty of intergrades between these "types."

Type 1. The straight line growth curve of the bi-acromial width is illustrated by Fig. 4 (below). Alongside is placed the developmental curve of stature for the same person. Both rise with remarkable straightness and uniformity from 10 to 17 years. In general, a comparison of a number of cases of straight line growth curves of bi-acromial width and corresponding growth curves of stature shows that where the one is linear the other is nearly so also. The boys of Type 1 are boys who show no extraordinarily great spurt of growth between 12 and 17 years.

Type 2. The second type of growth curve of bi-acromial width is of a shallow U-shape. It is illustrated in Fig. 5. A comparison with the curve of growth in stature shows that the bottom of the shoulder-width curve corresponds roughly with a point of increasing rate of growth of

stature. Most of these curves end before 18 years of age; they may be regarded as uncompleted examples of the following type.

Type 3. The third type of curve of development of the bi-acromial width may be called the concavo-convex (Fig. 6). Curves of this type usually include later ages, 17½ to over 19 years. A comparison with the development curves of stature shows that the latter include the period of slackening of growth that comes with late puberty.

In general, one may say that the development curve of shoulder breadth runs roughly parallel to that of stature; and a spurt, or retardation, in the one is apt to be reflected in the other, though not always simultaneously.

2. *Relative Bi-acromial Width*

a. Mass Statistics

The bi-acromial width in relation to stature is, in general in BOA Nordic boys from 6 to 14 years of age, a constantly diminishing ratio (Fig. 7). From 14 to 16 years the ratio appears to increase slightly.

FIG. 7. RELATIVE BI-ACROMIAL WIDTH
Mass statistics. Slightly smoothed. BOA Nordic ♂ ————. ♀ — — — — — —.

FIG. 8. DEVELOPMENTAL CURVES OF RELATIVE BI-ACROMIAL WIDTH
Mass statistics. ♂. Nordic (slightly smoothed) -----, Mediterranean — — —, Negro ————, Weissenberg's Jews ♂ +++++, Weissenberg's Jews ♀ . . . . .

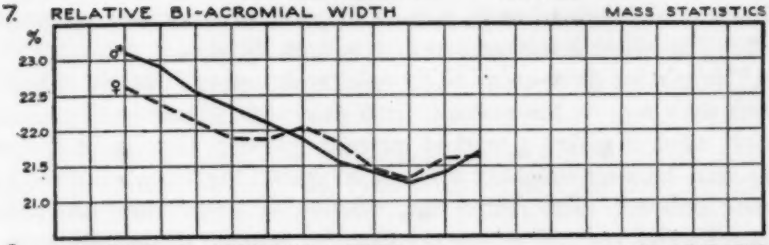
FIG. 9. DEVELOPMENTAL CURVES OF RELATIVE BI-ACROMIAL WIDTH
Individual statistics. ♂ a-a, G. M., LVD No. 99; b-b, H. M., LVD No. 104; c-c, L. M., LVD No. 106. The preceding three brothers of the M. family. d-d, C. H., LVD No. 83; e-e, E. H., LVD No. 1.

FIG. 10. DEVELOPMENTAL CURVES OF RELATIVE BI-ACROMIAL WIDTH, INDIVIDUAL, OF FOUR SISTERS OF THE M. FAMILY, SMOOTHED
a-a, M. M., 15 to 20 years —.—.—.—.; b-b, N. M., 12⅓ to 21⅓ years — — — — —; xx, precise ratios found. c-c, B. M., 6½ to 14½ years ————, oo, precise ratios found. d-d, R. M., 8½ to 17 years — — — — —, Δ Δ, precise ratios found.

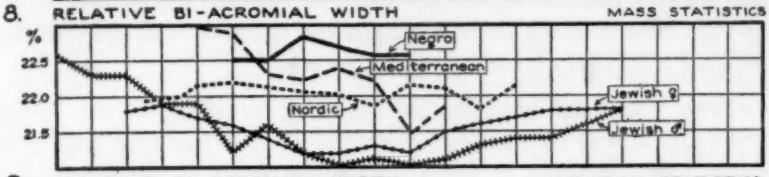
FIG. 11. DEVELOPMENTAL CURVES OF THE RATIO, BI-ACROMIAL WIDTH ÷ SITTING SUPRASTERNAL HEIGHT
Mass statistics. BOA Nordic ♂ ————, slightly smoothed. ♀ — — — — —, smoothed.

DEVELOPMENTAL CURVES

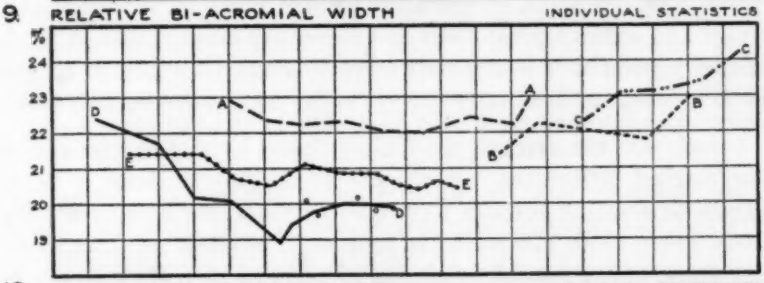
7. RELATIVE BI-ACROMIAL WIDTH — MASS STATISTICS



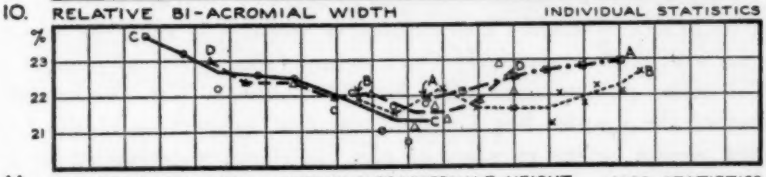
8. RELATIVE BI-ACROMIAL WIDTH — MASS STATISTICS



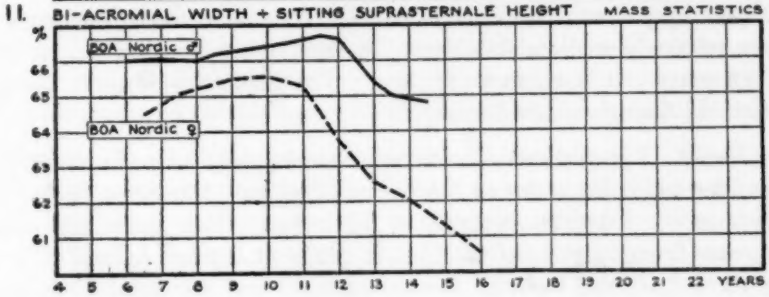
9. RELATIVE BI-ACROMIAL WIDTH — INDIVIDUAL STATISTICS



10. RELATIVE BI-ACROMIAL WIDTH — INDIVIDUAL STATISTICS



11. BI-ACROMIAL WIDTH ÷ SITTING SUPRASTERNALE HEIGHT — MASS STATISTICS



The bi-acromial width at 6 years is, on the average, about 23 p. c. of stature and falls to 21.25 p. c. at 14 years or about 0.22 points per year. Thereafter it increases to 21.7 p. c. at 16 years.

The relative decrease of bi-acromial width means that the shoulder width does not, on the average, keep pace with stature until after 14 years; when it makes a marked increase, growing faster than stature. The ratio becomes stabilized at about 20 years (Fig. 8) when growth is nearly finished. The reason why relative shoulder width diminishes from 6 to 14 years is apparently that the legs are during this period growing faster than the trunk in length and the growth of the shoulders is tied up with that of trunk and not of legs.

Sexual. In relation to stature the shoulder width of the average Nordic girl at 6 to 10 years is nearly half a point less than that of the average boy. At about 11 years the relative width of shoulders of the average girl makes a great spurt and thereafter exceeds that of the boy for 4 or 5 years; but is exceeded again by that of the boy at 16 years. The I. decussation is at 10½ years; the II. decussation at 16 years.

Social. On the average, the United States boys of the four groups show marked differences. While the BOA Nordic shows a relative decrease of shoulder breadth from 6 to 14 years, the boys of the LVD Nordic group show a remarkable constancy, at about 22 p. c., from 6 to 17 years, with a possible minimum of 21.75 at 16 years followed by a rise to 22.2 at 17 years. This contrast is probably in some degree associated with the comparatively short stature (short legs) of boys of the LVD series as compared with the BOA series. The developmental curve of the I series lies, for the most part, below that of the LVD series, except before 12 years of age. It shows a depression to 21.2 p. c. at 13 years. The Mongoloid dwarfs, with extreme low stature, have relatively medium shoulders. In them also a minimum is reached at 13 years. It is about 21.75 p. c. The Mongoloid dwarfs form a short, medium-shouldered group.

Racial. Fig. 8 shows the averaged developmental curves of relative shoulder width for males of Nordic and Southern European stocks and a group of American Negroes, LVD series. One notes the slight decrease from 22 p. c. of the Nordic group at 6 years to 21.8 p. c. at 13 years (referred to in the last paragraph) and the rapid diminution of the index in the case of Mediterraneans from 23 p. c. at 8 years to 21.5 p. c. at 14 years, followed by a slight rise to 21.8 p. c. at 15 years.

The curve of the Mediterraneans crosses that of the LVD Nordics at about 13¼ years. The Negroes on the other hand have a relative shoulder width that is approximately between 1 and 2 points greater than that of the Nordics at all ages; i.e. between 23 p. c. and 22.5 p. c.; with a juvenile and an adolescent low point.

Others have found the average relative development curve for various peoples. Weissenberg's results for male and female Russian Jews are given in Fig. 8 (below). On the whole, the proportions found by him are less than in my Mediterranean children, but the two curves run nearly parallel; and both show the reduction in the ratio from 6 to 14 years, followed by a rise. In Weissenberg's data on males the minimum is 21 p. c. at 14 years. The minimum for females is 21.2 at 11-12 years, a little earlier than for males. Obviously the minimum is correlated with the adolescent spurt; the acromial width lags behind stature.

In Godin's ('03, p. 135) French boys the relative bi-acromial width *increases* irregularly from 21 p. c. at 13½ years to 22 p. c. at 17½ years. Others have found the relative shoulder width for adults of various races; and some of the results are given in Martin ('28, p. 347-8). In general the adult female ratio is slightly less (½ to 1 point) than the male ratio. Some average male findings are: Norwegian, 22.3; North Chinese, 22.0; Japanese (medium build), 23.5; Somali, 20.0; Bushmen, 20.0; M'Baka, 22.0; Togo, 25.0; Colorado Indians, 22.5; Eskimo, 24.3.

In general, the shorter races are apt to have relatively broad shoulders, indicating that the shoulder is more conservative than total stature, and especially than leg length.

In general, in all races the relative bi-acromial width decreases to the adolescent period and thereafter rises slightly. The shoulders continue to increase in width after the legs have nearly stopped growing.

b. Individual Statistics

In general, there is one type of individual development curve for the relative bi-acromial width. This is the shallow U-shaped curve. In different individuals the bottom occurs at different ages, and the depth of the minimum in comparison with the maximum is very variable.

Sexual. Typical examples of individual developmental curves of bi-acromial width are given in Fig. 9. The ages range from 5 to 24 years. On the whole there is an obvious decrease of 2 to 4 points from the fifth to the eleventh year (or to the fifteenth year) and a rise of about 3 points from the minimum to 24 years. Interpreted, these curves mean that in the juvenile and adolescent periods the stature is growing faster than shoulder breadth; but after puberty sets in and

stature growth slows up the shoulders continue to increase in breadth for some years. In the case of girls (Fig. 10) there is a similar concave course of the relative bi-acromial width. The minimum probably occurs a year earlier than in boys—namely in the fourteenth year (instead of fifteenth year as in boys). The same interpretation of the concave curves applies as in the case of boys; only, adolescence is precocious. Also, the depression is not so pronounced and is mostly at a higher level (21-22 p. c.), doubtless due to the shorter stature of the girls.

3. *Bi-acromial Width in Relation to Trunk Length (Sitting Suprasternale)*

a. Mass Statistics

The bi-acromial width is roughly two-thirds of the sitting suprasternale height; i. e. the height of the trunk is about 1½ times the breadth of shoulders.

Sexual. The contrast between the sexes, on the average, is shown in Fig. 11. The male rises from 66 p. c. at 6-8 years, to 67 p. c. at the twelfth year, and then decreases to 65 p. c. in the fourteenth year.

FIG. 12. DEVELOPMENTAL CURVES OF RATIO, BI-ACROMIAL WIDTH ÷ SITTING SUPRASTERNAL HEIGHT, FOR THREE SOCIAL GROUPS BOA (A-A), LVD (B-B), I (C-C). MUCH SMOOTHED

FIG. 13. COMPARATIVE DEVELOPMENTAL CURVES OF THE RATIO, BI-ACROMIAL WIDTH ÷ SITTING SUPRASTERNAL HEIGHT
Mass statistics. LVD males. Nordic (smoothed) ----------
Mediterranean (smoothed) — — — —, Negro ————.

FIG. 14. DEVELOPMENTAL CURVES OF RATIO, BI-ACROMIAL WIDTH ÷ SITTING SUPRASTERNAL HEIGHT. (CONCAVE TYPE)
Individual. a-a, C. H., LVD No. 83; b-b, S. B., LVD No. 55; c-c, W. M., LVD No. 8; d-d, T. F., LVD No. 27.

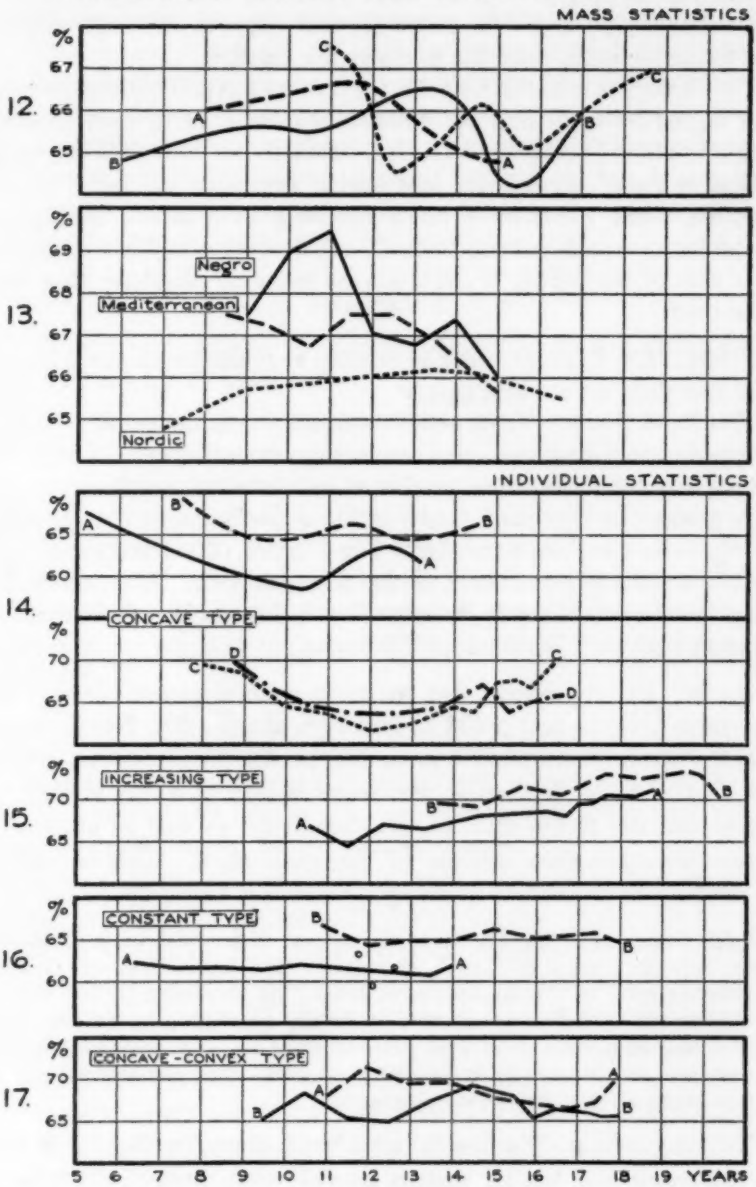
FIG. 15. DEVELOPMENTAL CURVES OF RATIO, BI-ACROMIAL WIDTH ÷ SITTING SUPRASTERNAL HEIGHT. (RISING TYPE)
Individual, for two boys; a-a, J. W., LVD No. 96; b-b, B. H., LVD No. 50.

FIG. 16. DEVELOPMENTAL CURVES OF RATIO, BI-ACROMIAL WIDTH ÷ SITTING SUPRASTERNAL HEIGHT. (CONSTANT TYPE)
Individual. a-a, R. O., LVD No. 110; b-b, C. D., LVD No. 46.

FIG. 17. DEVELOPMENTAL CURVES OF RATIO, BI-ACROMIAL WIDTH ÷ SITTING SUPRASTERNAL HEIGHT. (CONCAVE-CONVEX TYPE)
Individual. a-a, R. H., LVD No. 80; b-b, R. H., LVD No. 29.

DEVELOPMENTAL CURVES

BI-ACROMIAL WIDTH ÷ SITTING SUPRASTERNALE HEIGHT



In the female there is a similar rise from about 64.5 p. c. in the seventh year to 65.5 p. c. in the tenth year, and then a decline to perhaps below 61 p. c. in the sixteenth year—figures that are subject, however, to revision, since the numbers are small.

The important point is that the form of this relative developmental curve is *just the reverse of that relative to stature;* being convex above while the latter is concave. The developmental trunk-width curve in relation to trunk length states that during juvenility and early adolescence the trunk (shoulders) tends relatively to broaden, but during late adolescence and puberty it tends relatively to lengthen. But the upper part of the female trunk is always relatively slenderer than that of the male.

Social. The shoulder width in relation to trunk length for different social groups is shown in Fig. 12.

The BOA group (A) of males reaches a maximum of 66.7 p. c. at the twelfth year and then declines to the fifteenth year. The LVD group (B) of Nordic males reaches about the same maximum as the BOA group, but two years later. After a low point at the sixteenth year the ratio increases somewhat. The I series (C) is irregular, with possibly a delayed maximum at the fifteenth year. The curve for Mongoloid dwarfs is highly irregular, and is inverse in general trend to the more extensive BOA and LVD series.

Racial. Fig. 13 reveals that the average development curve of all these races between ages 7 and 16 is convex above. The Nordic maximum is lowest, occurs at 66.2 p. c., that of the Mediterranean groups is at 67.5 p. c., while that of the Negro is 69.5 p. c. It is clear in general that the Negro children have relatively, as well as absolutely, broader shoulders than children of European stock. This is true in relation both to stature and to sitting suprasternal height.

Godin ('03, p. 213) has determined the average bi-acromial width of certain French boys in relation to "length of trunk." The latter dimension is from suprasternale notch to symphysion (pubic arch). As the divisor is less than in our sitting suprasternale the quotient is larger, near 78 p. c. Godin finds that the ratio rises from 74 at 13½ years to 77 at 15 years, falls to 76 at the sixteenth year and rises to 77 in the eighteenth year. The post-pubertal rise of the ratio seems to be a wide-spread phenomenon.

To summarize: The trunk, considered alone (without legs and head-and-neck, and leaving aside a possible early juvenile decrease in

shoulders), broadens at the shoulders faster than it grows in length from the seventh to the twelfth or thirteenth year. Then the length grows the faster for two or three years. After that breadth at shoulders tends to increase slightly until the trunk stops growing; perhaps because the trunk length slows up as the man becomes "round shouldered" while use of the shoulders tends to broaden them. There is thus a rhythmic change in phase of growth, breadth-growth first exceeding length-growth in the preadolescent period and then falling behind at puberty. This broadening of the shoulders in children tends to take the child out of the anthropoid into the human status.

b. Individual Statistics

Several types may be distinguished in our series, but as we shall see they are not wholly independent.

The Concave Type. This is best seen in the curves of young children, 5 to 10 years of age. (Chas. H., LVD 83, Fig. 14, A). Here there is a steady decrease in the ratio from 65.6 p. c. at 5 years to 58 p. c. at 10½ years. This is followed by an increase to 12½ years. The curve of Stanley B. (Fig. 14, B) is somewhat similar; but the descent is not so great. More retarded are the phases in the curves of William M., LVD 8 (Fig. 14, C) and Tony F., LVD 27 (Fig. 14, D). The bottom of the sag is at 12 years, a year or two later than the minimum in curves A, B.

The Increasing Type. This is typically seen in the curves of Joseph W. (Fig. 15, A) and Benjamin H. (Fig. 15, B). It will be observed that these curves lie mostly in the later ages, corresponding to the rising limb of the concave type of Fig. 14. Clearly this is the later phase of the bi-acromial curve relative to trunk length.

The Level Type. This is especially interesting. It is well illustrated by the curves of Charles D., LVD 46 (Fig. 16, B) and Robert O., LVD 110 (Fig. 16, A). While irregularities appear in the profile they are probably mostly due to irregularities in posture and in pressure of the calipers. Charles D. shows a trace of a concavity, whose bottom is at 12 years (64.5 p. c.); but the rise from it to 17½ years (65.5 p. c.) is slight. In the case of Robert O., if one smooths the curve from 6½ to about 14 years a falling trend of about 2 points in 7½ years can be discerned. Absolute stability of the acromion sitting index is not to be expected and is not found.

Finally, there may be recognized the complex *concavo-convex* type which is perhaps a composite of the concave and increasing types and a new phase. At least one entire double (up-and-down) phase is included (R. H., Fig. 17, A); or there may be two phases, as in Robert H. (Fig. 17, B).

4. *Comparison of Developmental Change in Bi-acromial Width ÷ Stature and Bi-acromial Width ÷ Sitting Suprasternale*

Bi-acromial width ÷ stature between ages 8 and 16 years *falls* more or less regularly from 22.2 p. c. to 21.8 p. c. Possibly there is a tendency for this decrease to give way to an increase for a year or two at about 14-15 years.

Bi-acromial width ÷ sitting suprasternale between ages of 8 and 12 years *rises* more or less regularly.

This difference indicates that during this period the *trunk proper* at the shoulders tends to become *broader*; while (on account of rapid growth in leg length) the trunk at the shoulders tends, in relation to total *stature,* to become narrower.

5. *Summary*

The ratio bi-acromial width ÷ sitting suprasternal height is at ages between 7 and 19 years centered at about 66 p. c.; i. e. the shoulder breadth is about two-thirds of trunk height. Typically, the ratio tends, on the average, to increase slightly during childhood, to decrease during juvenility and to increase again as maturity is approached. There are exceptions to this formulation, but it is the one that is most widely applicable.

IV. THE GROWTH OF THE PELVIC WIDTH (INTER-CRISTAL WIDTH)

This is the distance measured by the anthropometer between the crests of the ilium at their greatest divergence from each other.

1. *Absolute Measurements*

a. Mass Statistics

Sexual. The absolute inter-cristal width of BOA Nordic boys increases on the average from 17.5 cm. at 6 years to 25.5 cm. at 16 years; an increase of 8 mm. per year. The growth curve is nearly linear.

However, there is apparently a period of more rapid growth, on the average at 4 to 6 years (11 mm. per year), and again at 12-15 years (9 mm. per year) than at the intermediate 8-12 years (7 mm. per year). With these data are in fair agreement the findings of Gray and Ayres as shown in Fig. 18, C.

In Nordic girls the cristal width is on the average less than in boys, ages 6 (18.5 cm.) to 9 years (20 cm.); but exceeds by about 1 cm. the boy after 12 years. These findings agree closely with those of Gray and Ayres, shown in Fig. 18, D. The increment curve rises sharply from 9 to 12 years (at which age the growth is at the rate of 16 mm. per year). Thereafter the rate of increase slowly diminishes. The increase in absolute width, on the average, from 10 years to 14 years, is from 20.7 cm. to 26.3 cm., a total of 5.6 cm. or over 25 p. c. In the male the corresponding increase is 21 p. c.

The age at decussation varies in different series. Thus in both Gray and Ayres' series for Private School children of the United States and that of Weissenberg for South Russian Jews the I. decussation is during the tenth year (Fig. 18).

A late near approach of the sex curves occurs in Gray and Ayres' series at 16 years; and in Weissenberg's series at 19 years; but the curves do not cross. Between the American children of Gray and Ayres and the Jewish children of Weissenberg there is a great difference, for in the latter the sex difference in inter-cristal width is about twice as marked as in the former at ages 13 to 15. Indeed, the marked increase in cristal width of Jewish girls from 11 to 13 years, of 13 mm. per year, is perhaps the most striking example we have of change in external proportions of the trunk dependent upon sex, as Martin ('28, p. 351) points out. In my BOA series there is no approach to a second decussation.

The sexual difference between the absolute inter-cristal width in adult pelves of the different Europeans is apparently not constant. Giuffrida-Ruggeri ('22, p. 188) finds that it is broader in the male in Letts by 21 mm.; in Russians by 13 mm.; in English by 11 mm. It is narrower in the male in Estonians by 2 mm.; in Parisians by 5 mm.; in Venetians by 8 mm.; in Bolognese by 7 mm. Also, the range in the mean is for European males: from Polish 27 cm. to Bolognese 30 cm., while that of the females is about the same.

Social. While, in general, the boys of the BOA series show the greatest mean cristal width, the males of the three other series in their early years exceed the males of the BOA series in this dimension. After the twelfth year the boys of the other series have an inferior width to those of the BOA series and this is only in part correlated with their smaller average stature. The Mongoloid dwarf males have an exceptionally broad pelvis after 13 years.

Racial. Before 13 years of age boys of the Mediterranean group have a greater absolute pelvic width than the Nordic boys. The Negro boys, on the other hand, have pretty uniformly narrow pelves (Fig. 19), —at 13 years, on the average, 5 mm. narrower than Nordics and Mediterraneans.

From a comparison of the means of cristal widths for different races of mankind as found by various authors, the following conclusions appear to be significant. In absolute cristal width the Bolognese, Letts, Jugoslavs and Norwegians have the largest pelvic diameters. The Maya Indians of Yucatan come next, despite their short stature. The peoples of Papua and Java have narrow pelves, while the Negroes have a pelvic width that is not perceptibly different from that of Papuans. If the pelvic width of the Baltic and Germanic people be taken as

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FIG. 18. DEVELOPMENTAL CURVES OF ABSOLUTE INTER-CRISTAL WIDTH. MASS STATISTICS
Below, Weissenberg's Jews, A ♂ ————, B ♀ — — — —. Above, Gray and Ayres' C ♂ ————, D ♀ — — — —.

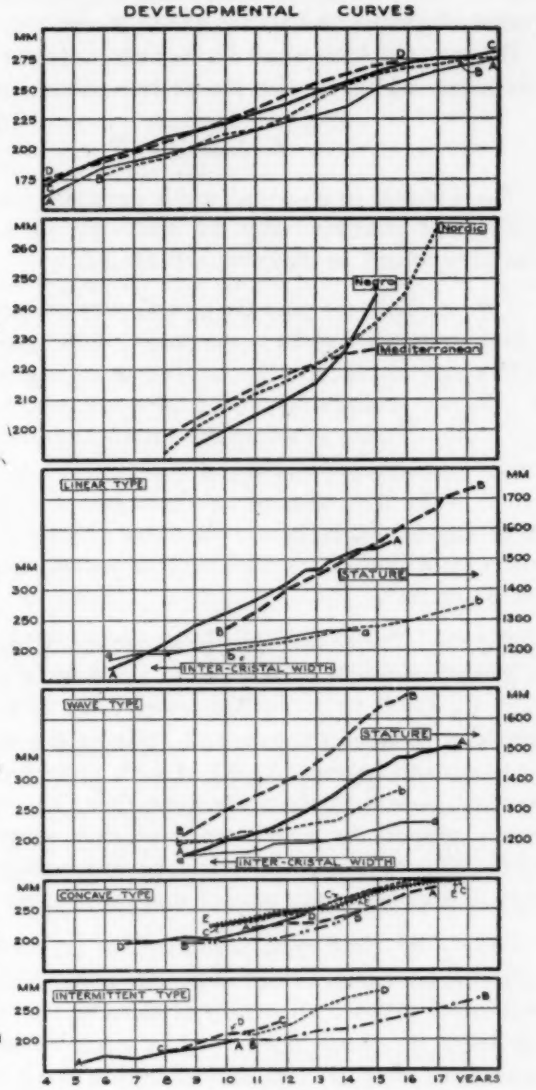
FIG. 19. DEVELOPMENTAL CURVES OF ABSOLUTE INTER-CRISTAL WIDTH, SLIGHTLY SMOOTHED.
LVD Nordic and U. S. -----, Mediterranean — — — —, American Negro ————.

FIG. 20. DEVELOPMENTAL CURVES OF ABSOLUTE INTER-CRISTAL WIDTH IN COMPARISON WITH DEVELOPMENTAL CURVES OF STATURES. (LINEAR TYPE)
Individual. a-a below, developmental curve of inter-cristal width of E. H., LVD No. 1; b-b below, developmental curve of H. M., LVD No. 43; A-A, developmental curve of stature of E. H., LVD No. 1; B-B, developmental curve of stature of H. M., LVD No. 43. Stature scale to right.

FIG. 21. COMPARATIVE DEVELOPMENTAL CURVES OF INTER-CRISTAL WIDTH, ABSOLUTE, (WAVE TYPE)
Individual. a-a, developmental curve of inter-cristal width of F. W., LVD No. 24; b-b, developmental curve of inter-cristal width of F. C., LVD No. 75; A-A, developmental curve of stature of F. W., LVD No. 24; B-B, developmental curve of stature of F. C., LVD No. 75.

FIG. 22. DEVELOPMENTAL CURVES OF ABSOLUTE INTER-CRISTAL WIDTH, INDIVIDUAL, OF FIVE LVD BOYS (CONCAVE TYPE)
a-a, C. D., LVD No. 46; b-b, C. G., LVD No. 63; c-c, F. B., LVD No. 23; d-d, S. B., LVD No. 55; e-e, W. E., I 15.

FIG. 23. DEVELOPMENTAL CURVES OF ABSOLUTE INTER-CRISTAL WIDTH, INDIVIDUAL. (INTERMITTENT TYPE)
A-A, C. H., ♂ LVD No. 83; B-B, R. B., ♂ LVD No. 81; C-C, M. K., ♀ BOA No. 83; D-D, A. M., ♀ BOA No. 87.


DEVELOPMENTAL CURVES
18.
ABSOLUTE
INTER-CRISTAL WIDTH
MASS STATISTICS
Solid Lines ♂
Broken • ♀
MM
275
250
225
200
175
19.
ABSOLUTE
INTER-CRISTAL WIDTH
MASS STATISTICS
MM
260
250
240
230
220
210
200
Nordic
Negro
Mediterranean
20.
ABSOLUTE
INTER-CRISTAL WIDTH
AND STATURE
INDIVIDUAL STATISTICS
LINEAR TYPE
MM
300
250
200
STATURE
INTER-CRISTAL WIDTH
MM
1700
1600
1500
1400
1300
1200
21.
ABSOLUTE
INTER-CRISTAL WIDTH
AND STATURE
INDIVIDUAL STATISTICS
WAVE TYPE
MM
300
250
200
STATURE
INTER-CRISTAL WIDTH
MM
1600
1500
1400
1300
1200
22.
ABSOLUTE
INTER-CRISTAL WIDTH
INDIVIDUAL STATISTICS
CONCAVE TYPE
MM
250
200
23.
ABSOLUTE
INTER-CRISTAL WIDTH
INDIVIDUAL STATISTICS
INTERMITTENT TYPE
MM
250
200
4 5 6 7 8 9 10 11 12 13 14 15 16 17 YEARS

29.5 cm., that of English as 29. cm., then that of American Negroes (United States Army at demobilization) is 28.5 cm. and that of full-blooded Negroes and Papuans about 26. cm.

Between the sexes there is, in most races, no difference in absolute inter-cristal width, despite the shorter stature of the females.

b. Individual Statistics

The absolute inter-cristal width naturally increases in the child as development proceeds. But the details of the course of that development vary greatly in different individuals.

Type 1. In some cases the growth proceeds with marked uniformity, as in Fig. 20, A and B, a composite of the growth curves of E. H., LVD 1 and H. M., LVD 43. Together these range from 6 years to 18. There is a slight rise in the thirteenth year and again in the seventeenth, representing probably the juvenile and adolescent spurts respectively. Also, the increments have diminished in the eighteenth year, as growth of the body as a whole slacks up. But aside from these slight, though significant, variations the curve of growth shows little departure from a right line. This type is characterized by uniformity, a smoothness of growth.

Type 2. The second type is illustrated in Fig. 21. This represents the growth of inter-cristal width in two boys, a (F. W., LVD 24) and b (F. C., LVD 75). In both cases there is a spurt in pelvic width growth in early adolescence and again at the onset of puberty. The stature-growth curves (A, B) of both these individuals show marked spurts of growth at about the same time; but the spurt of growth in stature precedes by about one year each spurt in growth in pelvic width. This type is characterized by waves of growth; and it is about twice as common as the type of uniform growth.

Type 3. A third type, shown in Fig. 22, may be called the concave type, since the curve, though in general rising, has a period of temporary cessation of growth. Generally at about 9, 10, 11 or even 12 years, the retardation of growth is followed by a much more rapid growth. This corresponds roughly with the adolescent spurt in growth but usually anticipates it by a year or two. Finally, the growth slows up, as we see in C (LVD 23) at 17 years. The complete cessation of growth of this dimension is often delayed till 20 years, or later.

Type 4. Intermittent. In the case of girls, as represented by C and D (Fig. 23) the slack growth occurs at about 10 or 11 years, and is followed by very rapid growth that carries absolute cristal breadth at 15 years to a point 5 mm. in excess of the breadth of most boys.

2. *Relative Inter-cristal Width*

a. Mass Statistics

Sexual. In Nordic boys (BOA) the inter-cristal width in relation to stature (Fig. 24) at 6 years is about 16.1 p. c., or a little less than one-sixth of stature, as contrasted with the 22 p. c. of relative shoulder width. It increases slightly to about 16.2 p. c. at early adolescence and then declines to about 15.7 p. c. at 16 years. The decline from 12 to 16 years is due to disproportionately rapid growth of leg length. There is probably an increase of the ratio after 16 years to 16.5 p. c. or more.

In BOA girls the average inter-cristal width at 6 years is about 16.1 p. c. of stature, just as in boys. The ratio then declines to about 15.6 at about 10 years. It then rises to about 16.5 p. c. at 16 years, and probably to a still higher ratio later. In general, the adult relative cristal width of women exceeds by about 1 point (1 p. c.) that of men —is about 17.5 p. c. In girls, accordingly, the minimum relative inter-cristal width is found at an age about 6 years earlier than in boys. This difference is apparently due to the great precocity in growth in pelves of girls as compared with boys.

Social. The relative inter-cristal width of the BOA boys is low, at least before 10 years of age, when contrasted with boys of inferior mentality (LVD); doubtless because they are taller (Fig. 24). The LVD curve is typically U-shaped. In the I series and still more in the M series the ratio is strikingly higher. At 16 years the ratio is about 15.6 in the BOA boys, 16.4 in the LVD series, 17.5 in the I series and 18.2 in the M series (a ratio found racially in the short South Tunguses of Siberia). As the legs shorten, on the average in these groups, the index increases.

Racial. The curve of growth of relative inter-cristal width of males from 7 to 15 years is always clearly U-shaped; the bottom of the U being at 13 to 15 years. That is, before that age inter-cristal width is increasing slower than stature as a whole and particularly leg length; after that (as legs slacken their growth and puberty sets in) cristal

width grows faster than stature, or legs. The curve of the Mediterranean males runs higher than that of the Nordics at all ages from 8 to 14 years. On the other hand, the colored boys have a much lower index; at 13 years as low as 14.9 p. c. (Fig. 25). This low ratio of the colored boys is, of course, due in part to their long legs; in part to their narrow pelves (Fig. 19). The Mediterraneans, with relatively longer legs than the Nordics, have more stocky proportions, have broader pelves, especially at juvenile and adolescent ages (Fig. 19).

The growth curve of the relative cristal width of Munich boys runs nearly parallel to that of our Nordics (Martin, '28, p. 352). In the Munich girls the ratio is lower than in boys from ages 8 to 14 (Fig. 26) and reaches a minimum at 11½ years. Probably a decussation comes later.

In the case of the Russian Jewish children (Weissenberg, '11) the relative inter-cristal width of the boys is at first greater than that of the girls (Fig. 26), but in the tenth year a decussation occurs and thereafter the relative pelvic breadth of the girls is progressively greater than that of the boys, so that at 19 years the girls have a relative pelvic breadth of 17.8 and the boys of 16.8 p. c. The minimum ratio is for girls at 9-12 years; for boys at 12-13 years.

The adults of various races vary in relative pelvic width, as shown in Martin's ('28, p. 351) table. Letts, who are of medium stature, are said to have a relative pelvic breadth of 16.2 p. c., Norwegians (tall) of 16.4 p. c., Bavarians of 17.4 p. c., South Chinese of 14.7 p. c., Japanese about 16 p. c., Bateva (pigmies

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FIG. 24. DEVELOPMENTAL CURVES OF RELATIVE INTER-CRISTAL WIDTH
Mass statistics. Nordic. BOA ♂ ————, ♀ — — — — —, LVD ♂ (smoothed) . . . . . .

FIG. 25. DEVELOPMENTAL CURVE OF RELATIVE INTER-CRISTAL WIDTH
Mass statistics. Smoothed. Races: ---------- LVD Nordic ♂, actual points ooooo; — — — LVD Italian ♂, actual points xxxx; ———— LVD American Negro ♂, actual points .....

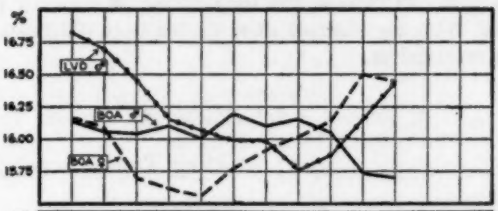
FIG. 26. DEVELOPMENTAL CURVES OF RELATIVE CRISTAL WIDTH
Mass statistics. Smoothed. Both sexes. ———— Weissenberg's ♂, — — — — — Weissenberg's ♀, — — — — — Martin (München children) ♂, ———— Martin (München children) ♀ ----------

FIG. 27. DEVELOPMENTAL CURVES OF RATIO, INTER-CRISTAL WIDTH ÷ SITTING SUPRASTERNAL HEIGHT
Mass statistics, both sexes. BOA, U. S. + North European, ♂ ————. ♀ — — — — —.

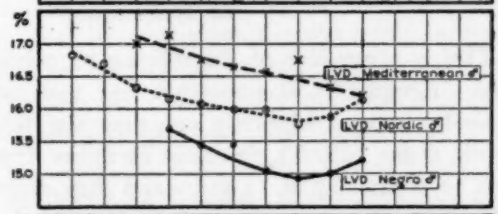
FIG. 28. COMPARATIVE DEVELOPMENTAL CURVES OF THE RATIO: INTER-CRISTAL WIDTH ÷ SITTING SUPRASTERNAL HEIGHT
Mass statistics of races. LVD ♂ Nordic — — — —, Mediterranean (smoothed) — — —, Negro ————.

DEVELOPMENTAL CURVES

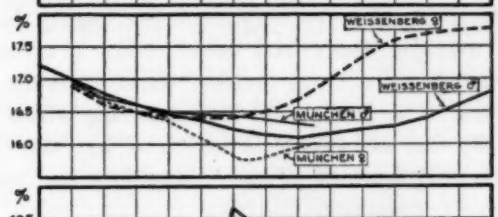
24.
RELATIVE.
INTER-CRISTAL WIDTH
MASS STATISTICS



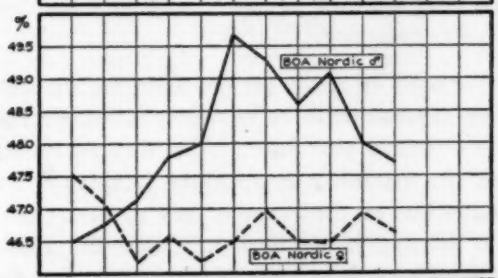
25.
RELATIVE
INTER-CRISTAL WIDTH
MASS STATISTICS



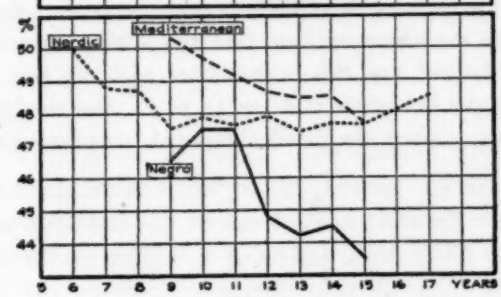
26.
RELATIVE
INTER-CRISTAL WIDTH
MASS STATISTICS



27.
RATIO:-
INTER-CRISTAL WIDTH / SITTING SUPRASTERNALE HT.
MASS STATISTICS



28.
RATIO:-
INTER-CRISTAL WIDTH / SITTING SUPRASTERNALE HT.
MASS STATISTICS



of Africa), of 14.2, Bushmen 16.4 p. c., Polynesians 17.6 p. c., Colorado Indians 17.0 p. c. In general the female ratio is 1 to 1.5 points higher than the male ratio. Also, the Negroes show the least sex difference, as they show the relatively narrowest pelves.

3. *Inter-Cristal Width in Relation to Trunk Length (Sitting Suprasternale)*

a. Mass Statistics

This is a measure of the relation of pelvic width to height of the torso. Roughly it is somewhat less than one-half of torso height. Somewhat more analytically one may say that, on the average, in the Nordic males (BOA) the ratio increases from about 46.5 p. c. at 6 years to about 49.7 at 11 years and then decreases to 47.8 at 16 years (Fig. 27). This can only mean that during the period 8 to 11 years, on the average, the cristal width (like bi-acromial width) is growing faster than the trunk height; while from 11 to 16 years the reverse occurs. The first period is that during which stature growth is almost wholly due to increase in length of leg, very little to trunk. Between birth and 6 years of age, there is some reason to think, the ratio diminishes slightly.

Sexual. In girls, on the average, the changes in the inter-cristal sitting-suprasternale ratio follow a similar course as in boys, but the phases occur a year later. Also they all lie at a lower level (Fig. 27). Thus the maximum at 12 years (comparable to the male maximum at 11) reaches, on the average, only 47 p. c. (as contrasted with the maximum of 49.7 in the male). Since the absolute cristal width of the girl at puberty is at least as great as that of the boy, this result accords with the observed fact that the sitting-suprasternale height is greater in the girl, and this is associated with the fact of more rapid growth of the girl in stature at 11 or 12 years than the boy. At this age the girl's torso is more elongated (longer if not narrower) than the boy's.

Social. Among the boys of United States origin those of the BOA show the most marked rise of this index up to 12-14 years (Fig. 27). The LVD boys, following a decline of the ratio in childhood, attain only about 48 p. c. during adolescence, but maintain or increase this ratio during puberty (Fig. 28). In the I series there are maxima in the ratio at 11 years (50.5 p. c.) and 14 years (50.5 p. c.). The ratio

goes still higher (52 p. c.) up to 19 years, which I interpret to indicate that the pelvic width of the idiots is still increasing after maturity. Finally, in the M series the ratio is still greater, rising to 54 p. c. at 17 years. The sitting height is low in this group. Also their tendency to lay on fat may modify the cristal width, as measured.

Racial. The Nordic LVD boys have an index at 12 years of about 48 p. c. (Fig. 28), comparable with 49.5 p. c. at 11 years of BOA boys. The Mediterranean group has a higher index at 12 years, namely of 48.6 p. c. We have seen that its relative inter-cristal width is greater also. The Negroes at the same age have an index of about 45 p. c.; due chiefly to their narrow pelves, as noted under absolute inter-cristal width. The curve of the average Negro index shows a marked decrease from 47.5 p. c. at 11 years to 44.5 p. c. at 14 years. This result suggests that in this race (as in less degree in the other races) the pelvis grows very slowly from 11 to 15 years, while the torso continues to elongate.

Comparative Racial. Apparently just this index has rarely, if ever, been computed. A few investigations have been made of the pelvic breadth in relation to Rumpflänge, which as defined by Martin ('28, p. 15) is suprasternale-symphysion, instead of sitting-suprasternale as used in this paper. This ratio will, of course, be larger than our ratio. Thus, v. Eickstedt ('26, p. 181) finds for the Garhwali in the Himalaya region, a pelvic breadth ÷ Rumpflänge of 53.8. Roth-Lutra ('28, p. 633) using the same index gets for "Rheinpfälzer" 56.9 and for amateur bicyclists of the same stock 58.8.

b. Individual Statistics

The individual study of the change in this index reveals four types.

Type 1. The U-shaped curve of index, changing with age. The lowest point of the U is between 10 and 11 years, the age before which the trunk height has been growing rapidly and after which the cristal breadth is growing rapidly.

Type 2. The type with decreasing ratio. The marked decrease corresponds in age with the descending part of the U type, except that in F. C. (C-C) descent continued to 16 years, as in mass statistics, suggesting that the sitting-suprasternale height was up to that time still growing faster than the cristal breadth. At 15-16 years growth of his cristal breadth nearly stopped changing for a year (Fig. 30) and then rose to 18 years.

Type 3. In this type the ratio gradually increases (Fig. 31). This may be because the individual was measured only after the age of lowest ratio as is the case with B. H. (A-A); or the individual's minimum occurred at an exceptionally late age as is apparently the case with F. C. (B-B) in which the curve finds its maximum at beyond 19 years.

Type 4. In this "wave" type there is no clearly significant change in trend of curve for some years (Fig. 32). The curves cover only about 6 years, occupying the middle period and showing considerable fluctuation. This group includes a residuum which has the most prolonged period of minimum ratio; mostly around 45 p. c.

To summarize: The cristal width of boys in relation to sitting-suprasternale height is high in late childhood; low in adolescence and again high in the pubertal period. There is, however, great variation in the size of the index (45 p. c. to 50 p. c. at 12 years) and in the

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FIG. 29. ABOVE, DEVELOPMENTAL CURVE OF RATIO, INTER-CRISTAL WIDTH ÷ SITTING SUPRASTERNAL HEIGHT (SCALE TO LEFT), SMOOTHED. (SEE FIG. 28, NORDIC). BELOW, INTER-CRISTAL WIDTH ÷ STATURE (SCALE TO RIGHT), (SEE FIG. 25, NORDIC). LVD No. 8

FIG. 30. DEVELOPMENTAL CURVES OF RATIO, INTER-CRISTAL WIDTH ÷ SITTING SUPRASTERNAL HEIGHT. INDIVIDUAL. (DECREASING TYPE)
a-a, W. M., LVD No. 8; b-b, A. D., LVD No. 38; c-c, F. C., LVD No. 45.

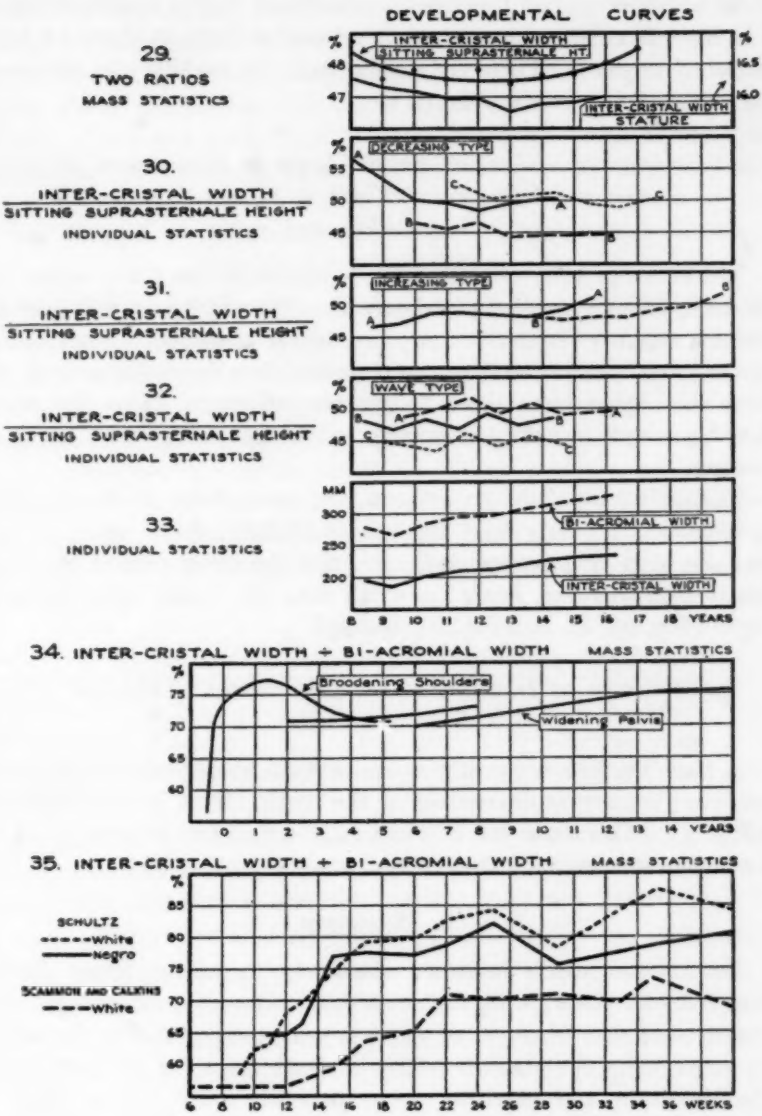
FIG. 31. DEVELOPMENTAL CURVES OF RATIO, INTER-CRISTAL WIDTH ÷ SITTING SUPRASTERNAL HEIGHT. INDIVIDUAL. (RISING TYPE)
a-a, B. H., LVD No. 50; b-b, F. C., LVD No. 75.

FIG. 32. DEVELOPMENTAL CURVES OF RATIO, INTER-CRISTAL WIDTH ÷ SITTING SUPRASTERNAL HEIGHT. INDIVIDUAL. (WAVE TYPE)
a-a, F. B., LVD No. 23; b-b, M. H., LVD No. 2; c-c, F. W., LVD No. 24.

FIG. 33. COMPARISON OF DEVELOPMENTAL CURVE OF ABSOLUTE INTER-CRISTAL WIDTH, BELOW, AND ABSOLUTE BI-ACROMIAL WIDTH ABOVE
Individual. E. H., LVD No. 79.

FIG. 34. DEVELOPMENTAL CURVES OF INTER-CRISTAL WIDTH ÷ BI-ACROMIAL WIDTH
Mass statistics. Nordic stock. Left, prenatal (Scammon and Calkins) 1-2 yrs. new data; 2-8 yrs. Wallis ('31), 6-16 yrs. LVD male data. Smoothed.

FIG. 35. DEVELOPMENTAL PRENATAL CURVES OF INDEX: INTER-CRISTAL WIDTH ÷ BI-ACROMIAL WIDTH
Data of Schultz, White ------, Schultz, Negro ———, Scammon and Calkins, White, bottom curve.


DEVELOPMENTAL CURVES
29.
TWO RATIOS
MASS STATISTICS
INTER-CRISTAL WIDTH
SITTING SUPRASTERNALE HT.
INTER-CRISTAL WIDTH
STATURE
30.
INTER-CRISTAL WIDTH
SITTING SUPRASTERNALE HEIGHT
INDIVIDUAL STATISTICS
DECREASING TYPE
31.
INTER-CRISTAL WIDTH
SITTING SUPRASTERNALE HEIGHT
INDIVIDUAL STATISTICS
INCREASING TYPE
32.
INTER-CRISTAL WIDTH
SITTING SUPRASTERNALE HEIGHT
INDIVIDUAL STATISTICS
WAVE TYPE
33.
INDIVIDUAL STATISTICS
BI-ACROMIAL WIDTH
INTER-CRISTAL WIDTH
8 9 10 11 12 13 14 15 16 17 18 YEARS
34. INTER-CRISTAL WIDTH ÷ BI-ACROMIAL WIDTH MASS STATISTICS
Broodening Shoulders
Widening Pelvis
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 YEARS
35. INTER-CRISTAL WIDTH ÷ BI-ACROMIAL WIDTH MASS STATISTICS
SCHULTZ
White
Negro
SCAMMON AND CALKINS
White
6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 WEEKS

degree of change from one period to another. In girls the curve of cristal width in relation to sitting-suprasternale height is situated about as in boys, but the maximum occurs somewhat later, at about 12 years instead of 11 years. There is a maximum in the twelfth year and probably a high point in late puberty.

4. *Comparison of Developmental Change in Inter-cristal Width ÷ Stature and Inter-cristal Width ÷ Sitting Suprasternale, Males (Fig. 29)*

The curve of inter-cristal width ÷ stature in the LVD series (cf. Fig. 24), differs from that of relative shoulder width in that it does not diminish regularly from 8 to 15 years, but is U-shaped. After having regularly decreased from 8 to 13 years, doubtless due to leg growth, the index rises again from about 13 years to 16 years. This rise comes after leg length is nearly stationary, while the pelvic width keeps on growing.

The early part of the growth curve of inter-cristal width ÷ sitting-suprasternale is nearly level or declines slightly; there seems to be a clear rise after adolescence; indicating that the lower part of the trunk also is then growing faster in width than the trunk as a whole in length (Fig. 29; cf. also Fig. 28, Nordic).

5. *Relation of Inter-cristal and Bi-acromial Widths in the Same Individual*

A close relation frequently exists between the growth of the upper and lower transverse dimensions of the trunk. This is well illustrated in Fig. 33. This topic will be more fully considered in treating of the bi-acromial-intercristal index.

6. *Summary*

Inter-cristal width increases absolutely in nearly linear fashion from 6 to 16 years; with slight childish and adolescent spurts. The female surpasses the male at about 9 years and probably thereafter; but at maturity the absolute width is about the same for both sexes. The Mulattoes have narrower pelves than the whites. Four types of growth of individual pelvic width can be recognized from nearly linear to wavy or intermittent. The spurts of increase in pelvic growth follow quickly spurts of stature.

The curve of relative inter-cristal width is U-shaped owing to rapid growth of legs during the period of the descending curve. But in relation to sitting-suprasternale height the pelvic width is high at 10 or 11 years when legs are growing rapidly, but the trunk linear growth is slight. Also, after adolescence pelvic width increases faster than trunk length. There is a correlation between growth in width of shoulders and pelvis. Various types of individual growth can be distinguished.

V. GROWTH OF INTER-CRISTAL WIDTH ÷ BI-ACROMIAL WIDTH (TRUNK WIDTH INDEX)

The ratio of pelvic width to shoulder width gives an important index of the shape of the torso. If the ratio were 100 p. c. the frontal view of the torso would be approximately rectangular (cylindrical); if less than 100 p. c. we speak of the person as broad shouldered, more nearly top-shaped; if more than 100 p. c. narrow shouldered or with broad pelvis—more nearly cone-shaped.

In general, this ratio increases during juvenility and adolescence, increasing in Nordic males from 70 p. c. to 75 p. c.; but, since the shoulders are always broader than the pelvic breadth, never reaching 100.

a. Mass Statistics

Sexual. In the average of male Nordic BOA's the trunk width index rises from 70.2 p. c. at 6 years to 75.3 p. c. at 14 years, where our data end (Fig. 36 E-E). It possibly falls after 14 years as the shoulders increase in breadth, with greater use, while the increase of the pelvic width slows down.

In girls, (Fig. 36 D-D) the index rises little during juvenility and adolescence, and is then 1 point below that of boys; because during most of this period their acromial width is absolutely greater than that of boys. But at or about 14 years this ratio in girls comes to exceed that in boys, due partly to a relative slowing up of growth in the bi-acromial width, and partly to the fact that inter-cristal width is greater than that of boys and still rapidly increasing, at a time indeed, when often it has nearly stopped growing in boys. At 16 years it is 76.3 p. c.

In Weissenberg's Jewish girls it had by 20 years reached 82 p. c. (Fig. 36 A-A). In our Elmira series of college women the maximum reached at 22 years is 81±1.5 p. c. In general, an average Nordic woman has a trunk width index about 4 to 8 points higher than an average man.

Schenk ('25, p. 17) finds for students at Marburg University an index for males, 76.4±0.31; for females, 81.8±0.62. Rohden and Gründler ('25, p. 53) find for adult "athletics," male, 75.6; female, 84.6; for asthenics, male, 79.4; female, 88.1; for pyknics, male, 81.4; female, 89.1. Giuffrida-Ruggeri ('22, p. 200) finds that this excess of the trunk-width index in the female is a strictly human trait; it is not found in other Primates. The pelvis of the human female shows the widest departure from the typical Primate form.

Social. The BOA boys have, at 6 years, the smallest inter-cristal ÷ bi-acromial width ratio, 70.2. The LVD boys (Fig. 36 C-C) have a higher ratio (narrower shoulders) as children and juveniles; but during adolescence the ratio falls below that of the BOA males about 3 points. This difference may be in part due to the "pick-and-shovel" work of even the 13 year-old LVD boys, which expands the shoulders. The I series remains high at about 76 and 77 p. c. and the M series still higher, 78 or 79 p. c. The acromial width of the I series is small and of the M series still smaller, and the inter-cristal width fairly large after 14 years. The male Mongoloids are effeminate in torso build; and more like the pyknics of Rohden.

FIG. 36. COMPARATIVE MEAN DEVELOPMENTAL CURVES OF RATIO: INTER-CRISTAL WIDTH ÷ BI-ACROMIAL WIDTH
A-A, Weissenberg's Russian Jews ♀ smoothed; B-B, Jews ♂ smoothed; C-C, LVD ♂; D-D, BOA ♀; E-E, BOA ♂; F-F, LVD Negro.

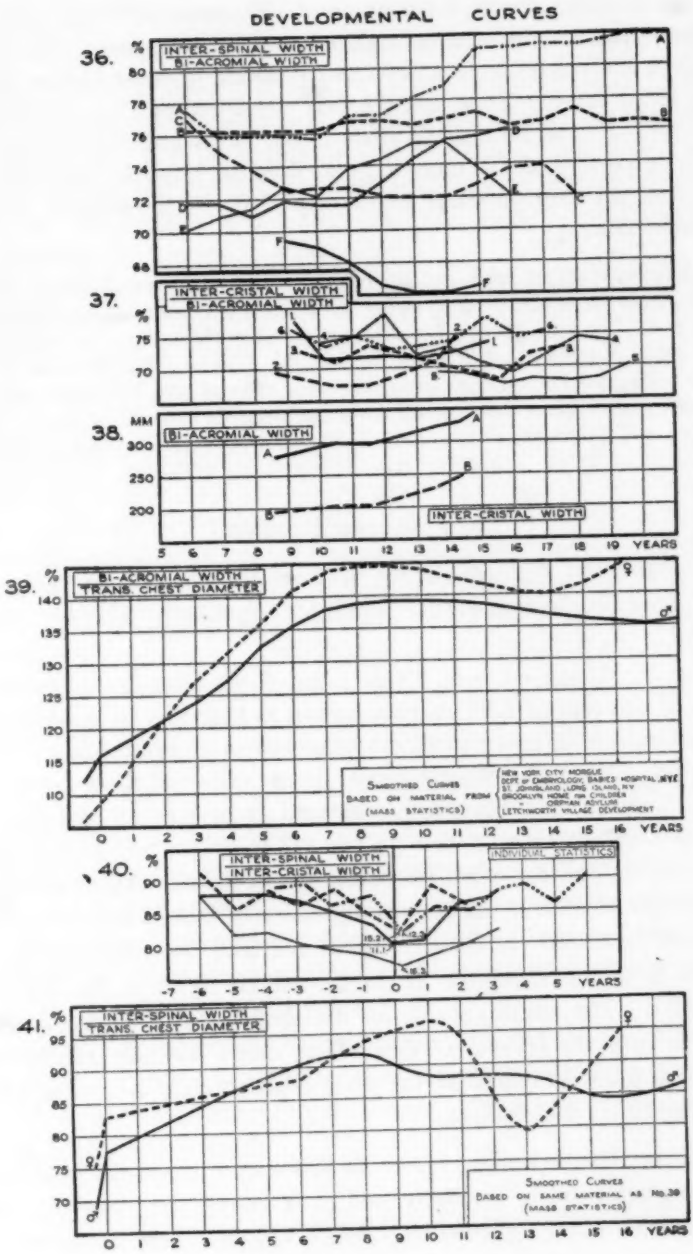
FIG. 37. SIX INDIVIDUAL CURVES OF RATIO: INTER-CRISTAL WIDTH ÷ BI-ACROMIAL WIDTH
No. 1, LVD 17; 2, LVD 63; 3, LVD 29; 4, LVD 38; 5, LVD 50; 6, LVD 16.

FIG. 38. COMPARISON OF DEVELOPMENTAL CURVES OF A-A, BI-ACROMIAL WIDTH AND, B-B, INTER-CRISTAL WIDTH OF ONE BOY, C. G., LVD 63

FIG. 39. SMOOTHED MEAN DEVELOPMENTAL CURVES OF RATIO: BI-ACROMIAL WIDTH × 100 ÷ TRANSVERSE CHEST DIAMETER
Mostly Nordic ♂ and ♀; based on data from N. Y. City Morgue, Department of Embryology (Streeter), Anatomy Department Cornell University (Stockard), Babies Hospital St. Johnsland, Brooklyn Home for Children, BOA and LVD data.

FIG. 40. DEVELOPMENTAL CURVE FOR FOUR MALE INDIVIDUALS OF THE RATIO: INTER-SPINAL WIDTH ÷ INTER-CRISTAL WIDTH; ALL CENTERED AT ABOUT THE SAME AGE; SHOWING U-SHAPED NATURE OF THE CURVES

FIG. 41. SMOOTHED MEAN DEVELOPMENTAL CURVES OF RATIO: INTER-SPINAL WIDTH ÷ TRANSVERSE CHEST DIAMETER
Mostly Nordic ♂ and ♀. Same sources as in Fig. 39.


DEVELOPMENTAL CURVES
36.
INTER-SPINAL WIDTH
BI-ACROMIAL WIDTH
37.
INTER-CRISTAL WIDTH
BI-ACROMIAL WIDTH
38.
BI-ACROMIAL WIDTH
INTER-CRISTAL WIDTH
YEARS
39.
BI-ACROMIAL WIDTH
TRANS. CHEST DIAMETER
SMOOTHED CURVES
BASED ON MATERIAL FROM
(MASS STATISTICS)
NEW YORK CITY MORGUE
DEPT. OF EMBRYOLOGY, BABIES HOSPITAL, NYC
ST. JOHNSLAND, LONG ISLAND, N.Y.
BROOKLYN HOME FOR CHILDREN
ORPHAN ASYLUM
LETCHWORTH VILLAGE DEVELOPMENT
YEARS
40.
INTER-SPINAL WIDTH
INTER-CRISTAL WIDTH
INDIVIDUAL STATISTICS
YEARS
41.
INTER-SPINAL WIDTH
TRANS. CHEST DIAMETER
SMOOTHED CURVES
BASED ON SAME MATERIAL AS NO. 39
(MASS STATISTICS)
YEARS

Racial. The Nordic boys in the LVD series have the relatively low inter-cristal ÷ bi-acromial ratio of 72 p. c. at 14 years. The Mediterranean LVD boys have a ratio that is about ½ point higher (but in the I series ¾ of a point lower) than the Nordics. In our Negroes (Fig. 36 F-F) the ratio at 14 years is 66. This low ratio is due both to narrow pelvis and still more to great shoulder breadth. All observers agree that the average trunk index (65-68 p. c.) is lower in Negroes than in whites.

In striking contrast with our findings are those of Wiessenberg on Russian Jews. In his series the ratio is rather constant in the male, mostly between 76 and 77 p. c. The female index becomes 5 to 6 points higher than the index of the male. Adult Nordics stand at about 75 p. c., the Siberian tribes at about 77 p. c. Giuffrida-Ruggeri ('22, p. 195) gives the large ratio of 98.0 for males and 107.9 for females of Bologna and 89.4 for males and 102.5 for females of Paris. If the technique used in obtaining these ratios is the same as mine, the trunk width index would seem to be an outstanding race differentiating trait.

b. Individual Statistics

Several types of change in the development of the ratio in the individual may be distinguished. They are classified and described as follows:

Type 1. U-shaped type. This is much the commonest type. Six curves of this type of LVD boys are given in Fig. 37. In three of them the minimum is at 10-11 years; in three others at 15-16 years. There would here seem to be two sub-types: the juvenile and the pubertal.

In all cases the ratio, which increased from infancy and then decreased, is still decreasing from 70 (or 75) to 67 (or 70) at 10½ or 15 years. After that the index increases, 3 to 5 points. That means that the shoulder breadth is still increasing relatively from 9 to 10½ (or 15) years and thereafter the cristal breadth increases the more rapidly.

This is well brought out in the growth curve of C. G., LVD 63, (Fig. 38). The great growth of the shoulders (bi-acromial width, A-A) at 10 years (period of descending ratio) and the steeper angle of growth after 11 years of the inter-cristal width, B-B, (period of ascending ratio) are obvious.

Type 2. The decreasing ratio. In this class of cases the bi-acromial width increases fairly regularly and at a faster rate than the inter-cristal width. It is illustrated by J. W., LVD 96. Here the bi-acromial

width rises quite rapidly while the inter-cristal width makes a uniform, though slow, growth. J. W. is a large boy who does heavy work.[1]

Type 3. The increasing ratio. In this class of cases the inter-cristal width increases fairly regularly and at a faster rate than the bi-acromial width. It is illustrated by J. C., LVD 49. This boy is a slow grower, slender and not muscular and not given to such heavy work as J. W. of the opposite type. His increasing shoulder width does not keep up with his increasing pelvic width.

In general, the trunk width ratio is a sensitive index to the relative development of shoulders and pelvis, and the shoulders especially react by increasing width to use of the arms in heavy work.

c. Summary

The trunk width index increases during juvenility and adolescence (Fig. 34). It makes its growth increment in girls more slowly than in boys. In the physically and mentally better developed boys the index is small, but manual labor expands the shoulders and results in a reduction of the ratio even in morons. The ratio is strikingly low in Negroes. Three types of individual growth are recognized, the U-shaped, decreasing and increasing. The decreasing type is found among manual workers.

VI. DISCUSSION

1. *The Early Ontogeny of the Bi-acromial Width and Its Probable Phylogenetic History*

The absolute ontogenetic changes in acromial width have been traced in the period: 6 to 18 years. There is, of course, constant enlargement. The changes in relation to stature have also been followed. In this the denominator is changing so rapidly and irregularly that the interpretation for shoulder growth is difficult.

It seemed probable that the transverse diameter of the chest might be a dimension that would be more constant and steady in its growth and so make a better unit than stature with which to compare the changing shoulder breadth.

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[1] Into this class I put: LVD 8, 19, 28, 41, 60, 93, 95, 96, 109. In these the inter-cristal width grows slowly, averaging about 8 mm. per year.

The developmental curve of the bi-acromial width ÷ transverse chest diameter is shown in Fig. 39 for both sexes. While during infancy the ratio is greater in the male; in the child from 2 years onward it is greater in the female. This result is apparently due to the fact that the chest diameter grows more rapidly, though steadily, in the male than the female, so that with this large denominator, the quotient is small.

In both sexes, in relation to the transverse chest diameter, the shoulder grows rapidly in width up to the tenth year in the boys, a year or so earlier in the girls. Thereafter for some 7 or 8 years the shoulders grow relatively slower than the chest, but as maturity is reached they grow more rapidly, perhaps in response to the manual and brachial labor that is being performed then. At any rate, our data on the growth of transverse chest diameter show a maximum increment for boys at 15 years; for girls at 12 years, in both cases 2 years before the minimum bi-acromial chest ratio is reached.

The human shoulder is remarkable in the fact that, in the adult, it is so broad that the arms are suspended on each side, as it were by a crane, so as to be able to swing readily ventral and dorsal of the vertebral column. This condition is due to the fact that the neck of the articular (glenoid) cavity of the scapula, the clavicle and the spine of the scapula are so elongated as to carry the humerus quite free of the chest. The scapula, indeed, comes to lie approximately parallel to the frontal plane when the "back is straightened." Thus in one adult subject (W. D.) the scapulae make an angle of only 27° with the frontal plane, when the clavicles are little removed from the quiescent horizontal. However, by raising the lateral ends of the clavicles they move dorsalwards and come into the plane of the scapulae whose median margins approach each other while their planes come to lie still more nearly parallel with the frontal plane. Thus it is easy for most normal persons to place their scapulae at an angle of 15°.

This position of the scapulae is not the same in the foetus as in the adult. Attention to this matter shows at once that, in the foetus, the glenoid cavity looks not laterally, as in the adult, but more or less ventrally. That is, the plane of the scapula makes a larger angle with the frontal plane in the foetus than in the adult.

In order to determine the ontogenetic changes in this angle I have made measurements on foetal material. For access to such material (dead) I am indebted to Dr. George L. Streeter, Department of Embryology, this Institution; Professor Charles R. Stockard, Cornell

Medical School; and Mr. William M. Ward, Director, New York City Mortuary. For living children within 2 or 3 months after birth I had access to the Babies Hospital, Medical Center, New York City. For comparison I measured certain older children at Letchworth Village.

The method of obtaining the scapular angle was to measure the bi-acromial width, (the clavicles being at rest and nearly horizontal) the interscapular distance, dorsally, between the vertebral edges of the scapulae at the level of the spine, and the width of each scapula along the spine to tip of acromial process. Then I found the angle whose cosine equals: ½ (bi-acromial width—interscapular distance) ÷ ½ sum of the widths of the two scapulae. This is the angle made by scapula with the frontal plane sought.

The results are still tentative because the data are limited and the technique not perfected, but so far as obtained they are as shown in Table 1.

TABLE 1

Scapular Angular Position in Foetal and Postnatal Material

Preserved in Alcohol			*Preserved by Cold*		
AGE CONCEPTUAL	N	SCAPULAR ANGLE WITH FRONTAL PLANE (AVG.)	AGE POSTNATAL	N	SCAPULAR ANGLE WITH FRONTAL PLANE (AVG.)
20-26 wks.	7	62° 55′	6- 8 days	2	60° 33′
27-40 wks.	6	55° 08′	10-13 days	3	44° 53′
			20-28 days	2	30° 50′
			Living		
			Babies Hospital	3	45° 41′
			Boys at L. V.	6	29° 37′
			Girls at L. V.	2	27° 50′

These results show that in the embryos of 5 to 6 months the scapulae form angles of nearly 63° with the frontal plane. After birth the angle diminishes with the age of the child to about half, say 30°.

What is the meaning of this progressive change in the angle of the scapula with the frontal plane? There is probably more than one inter-

pretation to be given. First is a physiological one. The foetus is certainly a better fit in the uterus and is more easily passed at parturition if the shoulders do not project far beyond the head; and this result is attained by the nearly perpendicular position of the scapulae.

Second, it is probable that in the early months of development the relation of parts is more nearly like that in the lower mammals, where the scapula is perpendicular to the frontal plane and the anterior appendages are, in the foetus, folded beneath the chest as, indeed, they are in the human foetus. In the lower mammals the fore limbs retain the ventral position; while in *Homo*, after birth, the head of the humerus is carried out laterally. This is the new, human, character and the last to appear in ontogenesis. The earlier human (foetal) stages represent those at which the lower mammals have finished their development. Thus the fact that human development parallels that of the lower mammals up to a certain point is evidence of the relationship of *Homo* to such lower Mammalia.

2. *The Early Ontogeny of the Ilium, Especially the Iliac Crest and the Anterior Superior Spine, and Its Probable Phylogeny*

The form of the human pelvis is unique in the mammalian series. While the "three spokes of the wheel" that center at the acetabulum are present in all, the form of the ilium and especially its crest, is peculiar to man. It is not that the human ilium is so broad; it is proportionally less broad than in the gorilla and the elephant. Its peculiarity rests in this, that the line of the crest is wavy.

Beginning at the anterior (ventral) end which flares slightly outward, the crest trends slightly inward toward the sagittal plane, thence outward in the great sweep of the concavity of the ilium, thence inward toward the anterior (ventral) margin of the sacral surface, thence outward to the posterior-superior spine. Disregarding the minor curves, the crest of the ilium shows, ventrally, a broad though shallow concavity toward the sagittal plane and then dorsally a great convexity toward the sacrum.

This, then, is the novelty; for in the gorilla the ilium makes one shallow concavity toward the sagittal plane, while in the orang and chimpanzee the ventral section of the crest extends out almost at right angles from the sacrum. The relations are shown in Waterman's ('29) Fig. 5.

The significance of the special shape of the human ilium and its crest have been discussed by various authors. In some way or other it is connected with man's erect posture. In consequence of that erect posture the weight of the viscera below the diaphragm is largely borne by the pelvis. Weidenreich ('13) especially has suggested that the new tensions resulting from abdominal (and other) muscles functioning in a new way have molded the pelvis. However, the view of the exclusively gravitational origin of the peculiar human ilium is untenable. The most that can be said is that the human pelvis has genetic elements that permit it to react to gravity as it does.

Of the homology of the crest of the ilium throughout the anthropoid apes and, indeed, the Primates, there can be little doubt. The same muscles arise from the crest,—the external and internal obliques, transversalis, latissimus dorsi, erector spinae, quadratus lumborum—as Waterman ('29, p. 611) has shown. The anterior-superior spine is comparable throughout the Primate and most of the mammalian series. To it are attached the inguinal ligament, the sartorius muscle and the tensor fasciae latae.

One result of all these curves in the human iliac crest is that the interval between the anterior-superior spine of the right and left sides is, in man, less than the inter-cristal distance. In other mammals the inter-spinal distance is the greatest transverse pelvic diameter. In them it is not easy to find the inter-cristal distance since it is not a maximum and is otherwise not a precisely defined dimension. Accordingly, if we wish to compare the pelves and the trunk width indices of the lower mammals with those of man we do better to compare the inter-spinal widths.

a. The Inter-spinal-Bi-acromial and Inter-spinal-Inter-cristal Ratios in Man and Their Ontogenies

Since in *Homo* the inter-spinal width is less than the inter-cristal width, the first ratio will be less than the trunk width ratio. In an 8 year old boy instead of 71 p. c. it may be 65 p. c. Also, whereas during the period 8 to 16 years the inter-cristal-bi-acromial ratio increases from 71 p. c. to 75 p. c. the inter-spinal-bi-acromial ratio decreases from 65 p. c. to about 58 p. c. That is to say, while the crests of the ilium are becoming bowed outwardly during juvenility and adolescence, the anterior-superior spines are relatively approaching each other.

This relation is, however, not a linear one. A study of male individual ontogenies from 6 to 19 years indicates a more complicated relation. As Fig. 40 shows, the inter-spinal width at the juvenile period is about 90 p. c. of the inter-cristal width. This ratio diminishes to a minimum of from 76 to 82 p. c. and then tends to rise again 5 points or more. This is very clear in the study of individual developmental curves, but less clear in mass data because the age of the minimum varies greatly, from 11 to 17 years. Thus, the average ratio at any year tends toward constancy.

However, from the averages of spine and crest diameters given by Konikow ('94) we get similar evidence of a U-shaped curve of this ratio. Also, the ratio is larger in the male than in the female. His figures may be summarized as in Table 2.

TABLE 2

Average Inter-spinal ÷ Inter-cristal Ratio. Homo. (Konikow, 1894)

AGE	MALE	FEMALE
Newborn	91.07	88.41
0 to 2 years	93.15	85.85
2 to 5 years	82.44	82.84
5 to 10 years	84.97	82.34
10 to 15 years	83.78	85.01
15 to 20 years	88.42	83.79

All these data unite in support of the conclusion that there is a period during adolescence, or puberty, of minimum ratio, when the inter-spinal diameter is relatively at a minimum and the concavity of the ilium is at a maximum. Before that time the anterior-superior iliac spines have more nearly the flatter gorilloid form; after that time the tip of the spine turns outward and downward as if under a traction of the sartorius and the tensor fasciae latae.

b. The Inter-spinal Width ÷ Transverse Chest Ratio

The foregoing conclusions rest on a ratio that is determined by two greatly varying and interdependent elements. In an attempt to render the measuring unit (denominator) more constant the ratio was com-

puted: inter-spinal width ÷ transverse chest diameter. The result (greatly smoothed) is shown in Fig. 41 for each sex. From birth on there is a steady increase in inter-spinal width in relation to chest diameter. This reaches a maximum in the case of males at about 7 years when the ratio is 92 p. c. The ratio falls, intermittently, reaching a minimum of 84.5 at 16 years, then increases again. The period 13 to 15 years is that of most rapid narrowing of the pelvic spine diameter. After 15½ years the inter-spinal width begins to increase again, owing to the out-turning of the tips of the spines.

In the female the adolescent maximum occurs at 10 years, when the ratio is 96.5 p. c.; then it falls rapidly to 79.5 p. c. at 13 years; then rises rapidly to 95 p. c. at 16 years. This corresponds to the establishment of the broader inter-spinal distance of the adult female as compared with the male. One may, perhaps, see in the widening of the ilium at the spines up to 7 (or 10) years a developmental process like that which goes on in the ontogeny of the anthropoids and eventually leads to their broad wing-like ilia.

The juvenile contraction of the interspinous dimension brings about the human bowl-like form of the pelvis. The final relative increase of the inter-spinal dimension is associated with the finishing outward turn of the tips of the anterior-superior spines. The phylogenetic stages are completed at puberty, the later changes establish the definitive human pelvic form.

3. *The Early Ontogeny of the Trunk Width Index*

The trunk index of *Homo* undergoes a series of changes with age which are epitomized in Fig. 34. In the early weeks, shortly after the scapulae and pelvis have been pre-formed in cartilage the pelvic width is relatively small, only a little more than half of the bi-acromial width (56 p. c. at 2.5 months).

During the first 5 or 6 months of gestation the pelvis broadens rapidly so that the ratio rises to nearly 71 p. c. at 5.7 lunar months and then more slowly to 75 p. c. at birth (Table 3).

From some measurements made on five living babies within 8 days of birth I can confirm the ratio of 75 p. c. obtained by Scammon and Calkins and others for trunk breadth ratio at birth.

On the other hand Kugler ('32, p. 482) obtained for the new born Swiss babies the very low indices of 67.8 for males and 65.8 for females. While she obtained a mean value for bi-acromial distance of 119 mm. (which is large), she obtained for

TABLE 3

Trunk Indices of Foetuses, Based on Scammon and Calkins (1929, pp. 201 and 153)

AGE (LUNAR MOS.)	2.5	3.1	3.65	4.3	5.0	5.7	6.55	7.3	8.3	9.4	10.00	mo
Crown—heel length, mm.	37	76	123	172	224	274	329	369	421	475	524	
Inter-cristal diam., mm.	5.2	9.7	16.6	24.9	33.2	41.8	50.7	57.8	66.4	78.6	88.2	8
Bi-acromial diam., mm.	9.2	17.2	28.0	39.2	51.1	59.0	72.3	81.5	95.7	107.5	128.1	11
Ratio: $\frac{\text{mean inter-cristal}}{\text{mean bi-acromial}}$	56.2	56.4	59.3	63.5	65.0	70.8	70.1	70.9	69.4	73.1	68.9	7

inter-cristal width mean values of 80 mm. for males and 78 for females (which are small). Hence the small index. One is forced to conclude either that the proportions of Swiss new born babies are different from those of the United States or that Kugler's technique is different from Scammon's and from mine.

On the other hand, Schultz obtains trunk-width ratios for the human foetus that are much greater than those by Scammon and Calkins (Fig. 35). Also, the index he obtains for whites at birth, 84, is extraordinarily high. The index for Negroes at birth is lower, about 80. In view of the fact that the pelvis in Negro children and adults is narrow it is interesting to find this racial trait at the twelfth week of gestation.

From measurements of some 18 babies, 2 to 107 days after birth, I find a trunk-width index of about 78 p. c. (Fig. 34). Some data of Wallis ('31) covering the period from 2 to 8 years are included in Fig. 34. From 6 to 16 years the curve is based upon my own data (mostly BOA).

A study of Fig. 34 leads to the conclusions, that in the later months of gestation the pelvic width is increasing faster than the shoulder width; that after birth, for a while the shoulders, released from intrauterine pressure and the adaptation to parturition, broaden for a time. The arms which, in the new born, are placed in front of the lateral position gradually assume the more strictly lateral position so as to hang free of the lateral outline of the trunk. After 3 or 4 years the pelvis begins to widen faster than the shoulders. Finally, experience indicates that with the use of the shoulders in hard manual labor, in the male, the trunk width index begins to diminish again.

An "explanation" of the small ratio of the pelvic width to shoulder width in early foetal life might be that based on the law of cephalization, to which C. M. Child has made valuable contribution. According

to this law metabolism proceeds most rapidly at the head end of the embryo; the growth processes of the caudal part of the embryo are retarded. Accordingly, the body of an adult fish, or a tadpole or vertebrate embryo of any sort, tapers off at the caudal end. This embryonic type is found in all of the Primate embryoes whose proportions are given by Schultz ('26, p. 480). He points out that in practically all young Primates the pelvic part of the trunk is narrower than the shoulders; in the adult the two dimensions tend to become nearly equal. There is an interesting question whether this change of shape is of phylogenetic significance, or is an instance of cephalization? Strictly, we do not have to face these questions as alternatives: both may be answered affirmatively.

There is no evidence of a mammalian progressive tendency toward increase of adult pelvis. The Primates have broad pelves in connection with their tendency to stand partially or wholly erect. The iliac flanges support the viscera and serve for attachment of the stout obliquus externus and internus and latissimus dorsi muscles. But the main "purpose" of the iliac flanges is to give room for the gluteal muscles. The broad pelvic bones, like the broad shoulders, have immediately adaptive proportions, but these are not called for full service until after birth.

4. *The Phylogenetic History of the Trunk Width Index*

To get data for a comparative view of the inter-spinal ÷ bi-acromial index in the different groups of mammals I visited the American Museum of Natural History, New York City, with my assistant Mr. William Drager, and obtained the consent of Curator H. E. Anthony to measure the pelvis and bi-acromion width in a number of mounted skeletons. The results are given in Table 4.

There is much of interest in the varied ratios shown in this table. First the position of adult *Homo* is far removed from his nearest relatives, chimpanzee and gorilla, just because in the latter the ilium is flaring; in the former contracted.

Striking is the enormous index of rhinoceros, bison and elephant. It is by virtue of their extensive pelves that elephants can be trained in the circus to raise their huge bulk and support themselves on their hind legs. In the sloth the broad pelvis provides support for the viscera when the animal is hanging in a horizontal position from the limbs of

TABLE 4

Interspinous-Bi-acromial Index (Skeletal) in Various Mammals

Rhinoceros	200	Native Australian	58
Bison	167	*Ornithorhynchus*	57
Indian elephant	150	*Manis javanica*	56
African elephant	133	*Homo sap.* Europ.	56
Sloth	120	*Sciurus malabarensis*	54
Dendrolagus (tree kangaroo)	100	*Felis dom.*	51
Gorilla	95	*Dasypus villosus*	49
Echnidna	93	*Cebus fatuellus*	48
Hystrix cristata	93	*Scutisorex congicus*	46
Perameles	90	*Notoryctes typhlops* (marsupial mole)	45
Giraffe	90	Virginian opossum	44
Ateles (spider monkey)	86	*Solenodon paradoxus* (insectivora)	44
Aard-vark	84	*Felis pardalis*	40
Chimpanzee	80/76	*Pteropus edulis* (bat)	37
Gazella dorcas	76	*Perodicticus potto* (Lemuroidea)	36
Macacus	74	*Nycticebus borneanus* (lemur)	28
Lemur	70	*Chrysochloris aurea* (African mole)	23
Phalangista (tree inhabiting marsupial)	65	*Pteropus edulis* (bat)	23
Scalops aquat.	65	*Desmodus rufus* (bat)	14
Mustela amer.	64		
Lemur variegatus	60		
Canis nubilis	59		

trees. One cannot, however, say the broad pelvis is the gravitational result of the attitude of the sloth; rather the broad pelvis permits the horizontal attitude. On the other hand the bat, *Desmodus,* like all bats, has an almost rudimentary pelvis and broad shoulders. Accordingly it hangs upside down so that the weight of the viscera is carried by the shoulders. The broad shoulders are, of course, necessary to flight. The bat adjusts its habits to the structure with which it finds itself provided. Burrowing mammals, like moles, have a large shoulder girdle and a small pelvis; the small pelvis does not interfere with the burrowing habit; the broad shoulder-girdle permits it, encourages it.

In the lithe walkers and runners, like wolves and cats, the shoulder and pelvic girdles are nearly equally developed. The Primates, as a whole, have well developed pelves and relatively small shoulders, which prevent them from becoming graceful walkers[2] while permitting them to use the pelvic limbs in tree climbing. The human combined traits of broad shoulders (leaving the arms free to pass to and fro by the chest and trunk) and narrow pelvis facilitate locomotion in the upright position.

The various forms of mammalian trunk-breadth are illustrated in Fig. 42.

The right hand column illustrates various stages through which the human passes in his development. One sees that these are stages which are passed through (and in part retained) by lower mammals.

Thus, the three month foetus has a trunk breadth index of only 50 p. c., about like that of certain lower mammals, e. g. the cat. The five month embryo has a 70 p. c. ratio, about the same as the lemur (No. 41). The 78 p. c. ratio found at birth is found also in the chimpanzee (77 p. c.); the 74 p. c. ratio is found in 7 year old children; the 76 p. c. ratio is found in adult males.

Thus, the human in its development progresses from a generalized median sized ratio to a fairly high one; one that places it not far below the higher Primates. In so far as many more primitive types stop developing at a stage in man's ontogeny beyond which he progresses, in so far *Homo* may be said to show a recapitulation in his trunk width ratio.

5. *Summary of Conclusions*

In relation to transverse diameter of chest the shoulders (Fig. 39) rapidly increase from the sixth month of gestation to the ninth year; during adolescence the process is reversed, but at puberty the shoulder width exceeds in growth. In females the curve of growth of this index

[2] The greatest iliac width has been found, by Mollison ('19, p. 98) for various Primates in percentage of rump length (suprasternale-symphysion) as follows:

Gorilla	66.5	*Macacus rheo*	25.
Homo	56.2	*Cercopithecus*	22.
Orang utan	52.8	Lemurs	22.
Chimpanzee	52.2	*Callithrix jacchus*	18.
Gibbon	48.4	*Nycticebus tardigradus*	18.
Papio cyan.	30.		

is steeper than in males. The widening of the shoulders depends in part on a change in the angle of the scapula with the frontal plane. From before birth to adolescence it tends to decrease from 60° to 30°. The shoulders thus change from the ungulate to the human type.

The pelvic width may be considered either as inter-cristal or inter-spinal—the latter is more useful for comparison with the lower mammals where the crest of the ilium is hard to distinguish. The pelvic spines tend to turn toward each other during early development, thus preparing the pelvis for its function in supporting the viscera in the erect posture.

The inter-spinal ÷ inter-cristal ratio in man grows in U-shaped fashion with the minimum at from 11 to 16 years.

The trunk index of man (as measured by spinal width) occupies a middle position in the mammalian series (Table 4). The largest mammals have a high index; the flying mammals the lowest. The human foetus passes in its development through a series of stages in which the index increases to near term (Fig. 42). This series parallels the conditions found in lower mammals. This is an additional fact for the recapitulationists.

The adult human shoulder is unique among mammals in its broad lateral extension permitting not only free lateral movements as in the apes, but even freer movement in front of and behind the vertebral axis. The scapulae when first well developed lie at an angle of 60°,

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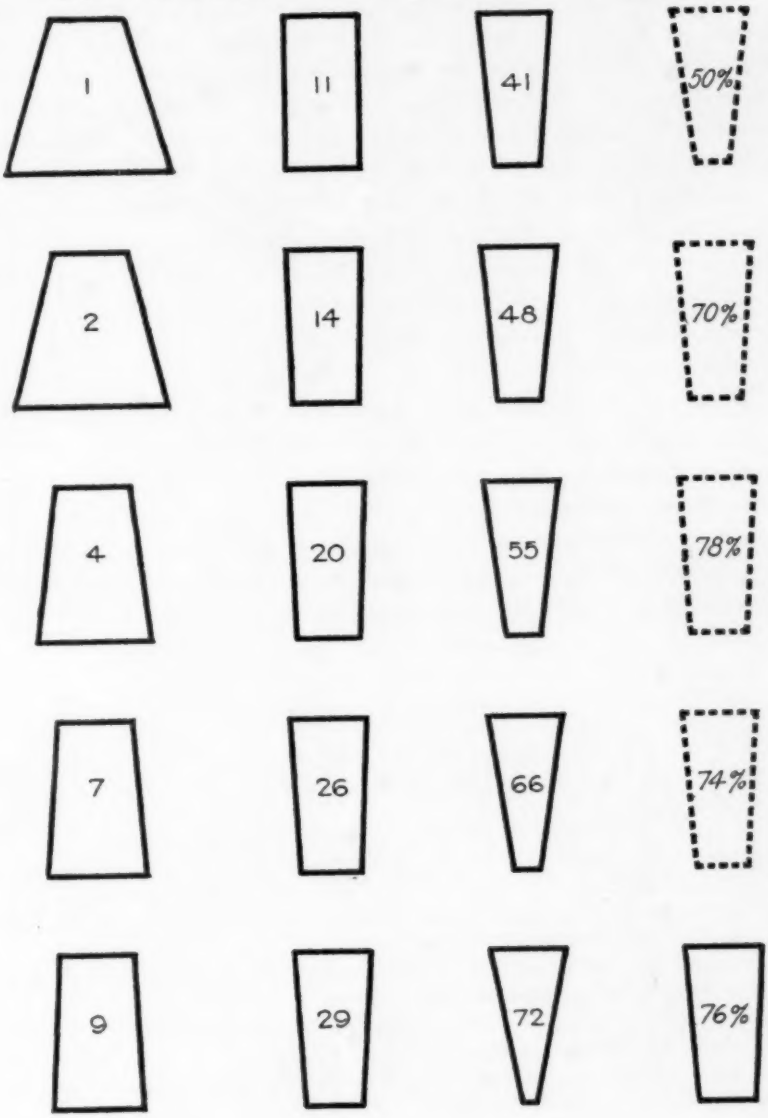
FIG. 42. APPROXIMATE FORM OF TRUNK IN 15 MAMMALS, SHOWING THE RELATION BETWEEN BI-ACROMIAL AND INTER-SPINAL WIDTHS; ALSO IN FIVE DEVELOPMENTAL STAGES OF HOMO

1, *Rhinoceros unicornis*; 2, *Rhinoceros bicornis*; 4, *Elephas indicus*; 7, *Mycetes seniculus* (Cebus monkey); 9, *Bradypus infuscatus* (sloth); 11, *Dendrolagus lumholtzi* (tree kangaroo); 14, *Echidna*; 20, *Tamandra tetradactyla* (arboreal ant eater); 26, *Ursus americanus* (bear); 29, chimpanzee; 41, *Lemur variegatus* (lemur); 48, *Homo sapiens*; 55, *Felis dom.* (house cat); 66, *Felis pardalis* (ocelot); 72, *Pteropus edulis* (bat).

The right hand column gives a number of stages in human development. The 50 per cent ratio of pelvic width to shoulder breadth is found in a three month foetus, also approximately in the cat. The 70 per cent ratio of pelvis to shoulder width is found in a five month embryo and also approximately in the lemur, No. 41. The 78 per cent ratio is found at birth and also in the chimpanzee (77 per cent); the 74 per cent ratio is found in seven year old children; the 76 per cent ratio is found in adults.

FIG. 42

COMPARISON OF
BI-ACROMIAL AND INTERSPINAL WIDTHS
IN FIFTEEN MAMMALS AND MAN



or more, with the frontal plane, at birth about 50° and in the adult about 30°. The acromial processes thus come to project laterally more prominently. This metamorphosis of the shoulders carries the child from the type of the lower mammals to that of *Homo*.

The adult human pelvis has a unique form among mammals. Instead of flaring ilia as in the adult Primates, the distal superior spines are turned toward the median planes and each other, more nearly completing the pelvic basin. Especially at adolescence does the inter-spinal distance cease its rapid growth while the inter-cristal breadth continues to grow, making the concavity of the ilia still deeper.

The course of growth of the trunk-width index is determined by the changes in width of shoulders and pelvis. While in the embryo this index is very small (under 60), it reaches a maximum of 75, or more, a few months after birth; apparently declines slightly as the shoulders broaden and then increases in adolescence as the pelvis widens: to participate, especially in the female, in the reproductive functions.

Thus from the fourth month of gestation to even past maturity the breadth proportions of the trunk are undergoing marked changes by which the embryo and child become adult. The upbuilding goes to a considerable extent along the lines of the upbuilding in other Primates and other mammals. But at an earlier or later stage the course of differential development becomes specifically human. Recapitulation in development is parallelism in development up to the point when each species begins to produce its differential traits.

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EUROPEAN RACES OF THE UPPER PALAEOLITHIC

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IT IS customary to speak of three races inhabiting Europe during Upper Palaeolithic times. The Cro-Magnon have been known longest. Three skeletons were found in the rock shelter of Cro-Magnon near Les Eyzies and were described in 1868 by Broca. Numerous others in France, Belgium, Moravia, Austria and Germany belonging to the same race have since been published.

In 1889, Testut investigated an almost complete skeleton found near Chancelade, and he came to the conclusion that this find represented a different race, which he called the race of Chancelade. The hypothesis that this race is more closely related to the Eskimos than to any other modern race has met with widespread approval but with only very few serious attempts at adducing proofs for it, among which Morant's paper ('26a) deserves special mention.

Again nearly 20 years later, Verneau ('06) examined the skeletal remains found in the caves of Grimaldi, and in the course of this work arrived at the conclusion that there were two among them which showed negroid affinities. These three races, the Cro-Magnon, Chancelade and the Grimaldi race, have become firmly established in all textbooks.

Recently Morant ('30) personally remeasured all the skulls from the Upper Palaeolithic period, thus correcting many data and descriptions. He could show that the variability of the whole series was no greater than in other races considered homogeneous, that in other words the assumption of only one race would account for the facts. At the same time, he was able to define clearly the craniometric characters in which the Upper Palaeolithics differed significantly from modern races of man.

It is the object of this paper to discuss the evidence from the rest of the skeleton (other than the skull) for or against Morant's theory. The present author was brought face to face with this problem when engaged in an investigation of the Cap Blanc skeleton now in the Field Museum of Natural History in Chicago. This is a practically

TABLE I

Some Measurements of the Cap Blanc Skeleton

Skull

L	greatest length	186
B	greatest breadth	142?
B′	least forehead breadth	99
B″	greatest forehead breadth	111?
S_1'	frontal chord	105
S_2'	parietal chord	121?
S_3'	occipital chord	102?
H′	basio-bregmatic height	138?
H	vertical height of head	138?
LB	length of base	104?
S_1	frontal arc	118
S_2	parietal arc	132?
S_3	occipital arc	121?
S	sagittal arc	371?
U	horizontal circumference through ophryon	519?
Q′	transverse arc through bregma	314?
NB	breadth of nose	23?
G_1	length of palate, from post. spine	41.5
G_2	breadth of palate, between second molars	34?
EH	height of palate	7

Long Bones

Humerus	R	L
max. length	309	300
least circumference	60	56
breadth at deltoid tub.	21.9	21.7

Radius		
max. length	231	229
least circumference	39	38
collo-diaph. angle	167°	164°
curvature of shaft	4.1	3.3

Ulna		
1 max. length		241?
3 least circumference		29
6 breadth of olecranon	24	..
7 depth of olecranon	21.5	23
8 height of olecranon	20	21
9 ant. breadth of radial half of art. facet of cor. proc.	8.5	8.5
10 post. breadth	10.6?	10.4

Femur	R	L
max. length	421.3	423.0
obl. length	419.5	420.0
infratroch. region:		
a.-p. diameter	21.6	21.3
transv. diam.	28.4	29.0
pilastric region:		
a.-p. diam.	28.0	28.6
transv. diam.	23.0	23.0

Tibia		
total length	344	348
max. length	352	354
platycnemic diameters:		
a.-p. d. 8a	34.2	34.1
transv. d. 9a	24.2	24.0

complete skeleton from the Magdalenian period and belonged to a young woman of about 20 years of age. The detailed report on it has just appeared (v. Bonin, '35), a few of the measurements used here are given in Table 1.

It should be emphasized that apart from this skeleton, most data used here have been published previously by others. Anybody actively engaged in osteometric work will be aware of the danger of pooling measurements made by various authors, particularly when these authors have not clearly and explicitly defined their mode of procedure. However, it was considered useful to see how far the information at present available will carry us, if only to get a clearer idea about the gaps in our knowledge. It will be seen in the course of our discussion that they are quite large and numerous.

This work has been done partly in the Department of Anthropology of Field Museum of Natural History, and partly in the Department of Anatomy of the University of Illinois. Furthermore, some of the material used has been gathered on a journey in Europe in 1931 made possible by a grant from the Bache fund. To the late Dr. Berthold Laufer and to Mr. Henry Field, to Dr. Otto F. Kampmeier and to the Trustees of the Bache Fund the writer wishes to express his sincerest gratitude.

SKULL

Nothing new has come to light within the last few years that would affect Morant's analysis of the male Upper Palaeolithic skulls, but to his list of female skulls the 'Brno III,' published by Matiegka, and the Cap Blanc skull should now be added. The revised means and constants of variability are given in Table 2, comparing the coefficients of variation, or, in the case of the indices, the standard deviations, with those of the English Farringdon Street series published by Hooke ('26), and with those of the *Crania Groenlandica* of Fürst and Hansen, the males of which have already been used by Morant. The contents of this table confirm Morant's conclusion that the Upper Palaeolithic type is surprisingly uniform as measured by statistical constants. Of the ten absolute measurements here listed, five are definitely less and the other five only insignificantly more variable in the fossil race than in the two modern ones. Of the two indices the cranial index shows a higher standard deviation in the Upper Palaeolithic series, but again only insignificantly so, amounting to 2.1 times its probable error in the case of the Eskimo. The index 100B′/B is again less variable in the fossil population.

TABLE 2

Revised Means and Constants of Variation for Female Upper Palaeolithic Skulls, With Some Comparative Data

CHARACTER	UPPER PALAEOLITHICS			FARR. STREET	ESKIMOS
	Means	S. D.	C. of V.	C. of V.	C. of V.
L	185.6 (12)*	4.90± .67	2.64± .36	3.69±.13	2.91±.11
B	138.2 (13)	6.23± .82	4.51± .60	3.74±.13	3.47±.13
B′	97.3 (13)	3.75± .50	3.85± .51	4.26±.14	4.72±.18
B″	117.6 (13)	6.90± .91	5.87± .78	.....	4.40±.16
S'_1	109.0 (10)				
S'_2	116.5 (11)				
S'_3	99.2 (8)				
H′	132.4 (9)				
H	132.7 (6)				
LB	100.1 (9)				
fml	36.4 (5)				
fmb	29.6 (6)				
S_1	125.2 (13)	6.23± .82	4.98± .66	5.43±.19	4.31±.16
S_2	127.7 (14)	8.10±1.03	6.34± .81	6.31±.21	6.31±.24
S_3	121.0 (10)	6.25± .94	5.17± .78	6.21±.22	6.62±.25
S	372.9 (10)	11.12±1.68	2.98± .45	3.58±.13	4.17±.16
U	524.6 (11)	19.33±2.78	3.68± .53	3.09±.11	2.57±.10
Q′	306.2 (7)				
NB	25.6 (10)	1.95± .29	7.62±1.15	8.00±.43	8.47±.32
G'_1	41.9 (2)				
G_2	37.2 (5)				
Indices				S. D.	S. D.
100B/L ...	74.9 (11)	3.95± .57	.....	2.96±.11	2.73±.10
100B′/B ...	70.3 (12)	2.63± .36	.....	.....	3.45±.13
100H′/L ...	71.9 (9)				
100B/H′ ...	104.9 (9)				
100(B-H′)/L	3.4 (9)				
$100G_2/G_1$ ..	85.3 (2)				
$100EH/G_2$.	33.8 (4)				

* The figures in brackets denote the number of cases on which the means are based.

TABLE 3

Sex Ratio for Some Series of Skulls

	UPPER PALAEOLITHICS	TEITA *	ENGLISH *	"ALTBAY-ERISCH" *	EGYPTIAN "E"
L	1.067	1.046	1.040	1.041	1.047
B	1.029	1.024	1.049	1.045	1.025
B′	1.013	1.039	1.038	1.049	1.027
S	1.058	1.040	1.046	1.033	1.034
U	1.047	1.042	1.044	1.046	1.038

* After Kitson.

In view of what we shall have to say subsequently about the sex ratio of stature, it may be of interest to compare male and female means of skull measurements. Considering only means based on ten or more skulls, we obtain the values given in Table 3 and compared there with those taken from the paper by E. Kitson ('31). The Upper Palaeolithic sex ratio is very near modern series for the horizontal circumference, but the male and female means are nearer each other for the least frontal breadth, and further apart for the greatest length and the sagittal arc. The head breadth shows much the same ratio as the Negro ('Teita') and the long Egyptian "E" series, but differs from that given for Europeans. The evidence is thus conflicting, but it would probably be reasonable to infer that our fossil samples are still too small for numerical work of this nature.

STATURE

But we turn away from the skull and consider first the stature of the Upper Palaeolithics. Probably nowhere in human palaeontology has there been more exaggeration than in estimating the stature of the Upper Palaeolithic people. Even Broca ('68) widely over-estimated the stature of the Old Man of Cro-Magnon, and for some of the Grimaldi skeletons figures of over 190 cm. have been given. Later workers, however, scaled down these estimates although, as we shall see, probably insufficiently. Most of these evaluations are due to French scientists and have been made either by applying Manouvrier's *"tableau barrême"* ('92, '93) or by computing body height by means of Rollet's ('89) coefficients. Only some English writers, notably Karl Pearson himself and Sollas ('24), have used Pearson's ('98) regression for-

mulae, the greater reliability of which has repeatedly been pointed out. It is true, these formulae may not predict the true stature in individual cases, for they are meant in the first place for computing the mean stature from the mean lengths of the long bones. We shall use them here, however, for individual skeletons in order to obtain data from which to calculate the variability of stature as well as its average. The errors of individual predictions should cancel out in a long series, and even in such a short one as has been gathered here, it should lead at least to a provisional estimate of statistical constants.

From the published data on the long bones we compute the statures by means of Pearson's formulae, using however only some of them, since the data are too defective to allow all of them to be applied. Taking then, the mean of each row—a procedure which is again open to criticism, since the different formulae have different sampling errors—we finally obtain the most likely stature for each skeleton. This work is shown in Table 4, at the bottom of which are cited further the esti-

TABLE 4

Reconstruction of Male Statures

	BAUSSO DA TORRE I	BAUSSO DA TORRE II	GROTTE DU CAVILLON	GROTTE DES ENFANTS	BARMA GRANDE I	BARMA GRANDE II	OBERCASSEL	CHANCELADE	CRO-MAGNON	COMBE CAPELLE	LAUTSCH	
F	....	....	....	180.2	182.3	174.0	165.3	....	....	161.2	....	
T	178.5?	....	176.6	185.1	182.3	174.2	174.4	....	168.5	....	....	
H	....	175.7	169.6	177.4	178.9	173.1	163.5	157.5	168.2	161.2	170.5,	171.4
R	....	172.3	172.0	....	179.5	....	172.0	....	....	....	....	
(F+T)	....	....	....	184.2	184.0	175.0	169.8	....	....	....	....	
F, T	....	....	....	184.0	184.0	175.0	169.5	....	....	....	....	
F, H	....	....	....	180.0	181.9	174.3	164.4	....	....	160.9	....	
Mean	178.5	174.0	176.1	181.8	181.8	174.3	168.4	157.5	168.4	161.1	171.0	

F: Femur; T: Tibia; H: Humerus; R: Radius.
Solutré: 183, 175.

mates for two male skeletons from Solutré, published by Depéret, Arcelin and Mayet ('23) and computed by means of Rollet's coefficient. These estimates are probably somewhat too high. We may then state finally that the male mean stature of the Upper Palaeolithic race was about 173 cm., with a standard deviation of 7.41 ± .94 cm.

The standard deviation is not significantly larger than those of other longer series of modern populations,[1] but it is nevertheless uncomfortably high. Moreover, the distribution is very irregular, but the small size of the sample may, of course, account for that.

Turning to the female values, we obtain the following estimates for the two skeletons which appear in Table 5. These, together with the Cap-Blanc skeleton and two female skeletons from Solutré, lead to a mean female stature of 155 cm., and a sex ratio of 1.116.

For ten modern races taken from Martin's *Lehrbuch* we obtain a mean sex ratio of 1.0813, with a standard deviation of .0121. In other words, the Palaeolithic ratio is 2.87 times the standard deviation larger than the mean, an occurrence which is to be expected in one out of 645 samples.

TABLE 5

Reconstruction of Female Stature

	GRIMALDI	OBERCASSEL
F	157.6	159.7
T	160.4	....
H	151.6	147.5
R	159.1	....
(F + T)	159.2	....
F, T	159.2	....
F, H	155.7	155.6
Mean	157.5	154.3

Solutré: 154, 154
Cap-Blanc: 156

[1] Hannesson's Icelanders ('25) have 5.73 ± .09 cm., one of the lowest values that has come to our notice.

Obviously, the fossil race does not fit in. The female sample, being quite inadequate, may have led to an underestimate, or we may have met with a particularly tall family (in the widest sense of the word) in the caves of Grimaldi leading to an exaggeration of the male stature, or, finally, stature may indeed have shown an exceptionally high variation. We see no way of deciding between these possibilities, but even granting that stature had a higher variability than is compatible with homogeneity, what should be concluded from that? Remembering that stature has increased quite considerably in some modern peoples during the last century, it would not be astonishing to find a high variation in a sample drawn from a period which must have lasted several thousand years. On the other hand, it is known that two populations may differ in stature, and yet have almost identical skulls. As an example, the "Malayans" from Java and the Aëtas from the Philippines may be cited (v. Bonin, '31). It is then a fine point whether we should regard these as two different races, or whether they are rather to be looked upon as two strains of one and the same race; a point upon which unanimity between anthropologists has hardly yet been reached. At any rate, taking everything into consideration, from the roundabout way in which the statures were found to our last remarks, no argument against the thesis that all the upper Palaeolithic individuals known thus far belonged to the same race can be built on the variability of their stature.

LONG BONES

Similarly, the proportions of long bones can be studied only on a narrow basis, since only a few complete skeletons are available. The data are given in Table 6. We shall consider first the male values given in the upper part of our table. To work out the standard deviations of such small samples is obviously futile. It appears better to examine whether or not values of this constant known from longer modern series can be considered reasonable approximations for our samples. We can compute their range in terms of the known standard deviations, the expected values of which were tabulated by Tippett. (See *Tables for Statisticians and Biometricians,* Vol. II.) Gauging the homogeneity of our data in this manner, only the femoro-humeral and humero-clavicular indices appear to be homogeneous, at least if we suppress the values for Bausso da Torre I. Both the humero-radial and femoro-tibial indices show a much larger range than would be expected in such a small sample. It is interesting to see that in both

TABLE 6

Proportions of Long Bones of Upper Palaeolithic Skeletons

	100 R/H HUMERO-RADIAL	100 T/F FEMORO-TIBIAL	100 H/F FEMORO-HUMERAL	100 Cl/H HUMERO-CLAVICULAR
Males—				
Bausso da Torre I	...	79.2	61.5 ?	51.2 ?
Bausso da Torre II	72.7	...	...	...
Grotte du Cavillon	76.3	88.8	73.7	46.2
Grotte des Enfants	76.4	85.7	70.6	46.0
Barma Grande I	76.5	82.0	70.3	43.0
Barma Grande II	...	81.9	72.1	45.5
Obercassel	81.9	90.8	72.3	...
Chancelade	...	...	73.5	...
Combe Capelle	...	89.8	74.0	...
Mean	76.8	85.5	72.4	45.2
σ of known series	2.1 *	2.0 †	2.2 †	2.0 *
Range (in terms of σ)....	4.4	5.8	1.7 ‡	1.6
Expected range (in terms of σ)	2.33	2.70	2.70 ‡	2.33
Females—				
Cap-Blanc:				
R	74.8	82.0	73.7	...
L	76.3	82.9	71.4	...
Grimaldi ♀	80.1	83.9	67.05	...

* Naqada (Warren)
† Indians of Pecos Pueblo (Hooton)
‡ Excluding the value for Bausso da Torre I.

cases the man from Obercassel is farthest removed from the mean, and it is hard to avoid the conclusion that after all, we have to deal here with unusually variable characters if the original data can be trusted. Again, it would be rash to jump to the conclusion of various racial strains (the reader will note moreover, that all the values of our table refer to the so-called Cro-Magnon race), and another explanation might be looked for. Are we to infer then that even at this late stage of phylogenetic

development the proportions of the limbs—a character in which man differs from all other anthropoids—had not yet become stable?

The female values of Table 6 add nothing new as far as the first two rows are concerned. They are all within the range of the male figures, although it is to be noted that the humero-radial index of the woman of Grimaldi is high, yet not as high as that of the man from Obercassel. On the other hand, the femoro-humeral index of the Grimaldi woman is lower than any other one, if we except again the value for the first skeleton from Bausso da Torre. The femoro-humeral index is the first instance in which we find the woman from Grimaldi definitely removed from the other Upper Palaeolithic skeletons, and it will be remembered that this fact was adduced by Verneau in support of his "Negroid" hypothesis. So long, however, as we only have samples as small as the one we have to deal with here, it seems hardly justified to exclude one skeleton from the rest on the strength of one character alone.

Turning to the means of Table 6, we can compare them with those of modern races. The pertinent data have been assembled by Martin in the first volume of his *Lehrbuch,* on pp. 395, 418 and 429, respectively. While all proportions of the upper Palaeolithics are within the range of modern man, they are yet quite near one end of the distribution of tibiofemoral and humerofemoral indices. Both their tibia and their humerus are long as compared with their femur. They share this feature in the first instance with most "primitive" races, Africans, Australians, and Amerinds, in the second instance with Europeans and Ainus. The humero-radial index is much nearer the interracial mean (we obtain from Martin's table, '28, p. 395 an unweighted mean of 77.0), and stands between the Europeans and "primitive" races. At any rate, these data can hardly be construed as an indication of specific 'negroid' affinity.

We have the claviculohumeral index in only four cases, if we exclude once more the improbable value for Bausso da Torre I: judging by its mean value, the Upper Palaeolithics must have been of quite slender build, since their index is near the lower end of the interracial range (51.5 to 44.3, Davidson Black, '25, excluding the value for the pygmy Andamanese).

After this discussion of the "general" features of the skeleton, it would obviously be our further task to take up in its turn each character of the long bones, to examine its variability among the Upper Palaeolithic individuals, and to investigate finally its behavior among

modern races. But—perhaps fortunately for the reader whose patience may be taxed heavily as it is—this cannot be done, for the simple reason that our knowledge is still far too incomplete. Hence, we shall consider in the following pages only a few characters which hold out some hope for results. In several instances a comparison with Neolithic material will be possible. Not aiming at completeness, we have here collected data on series from the north of France, and from Chamblandes, near Lausanne.

Craniological studies of these series are impeded in many instances by the scarcity of material, but so far as can be ascertained there appear to be no significant differences regarding L,* B,* B'* and 100B/L* between the male skulls from Les Mureaux, Châlons-sur-Marne and the Grotte des Fées, while the skulls from Chamblandes have a significantly smaller B than those from the Grotte des Fées (α (B) = 12.96).

Almost the only character of the humerus which can be studied is its relative thickness, determined by an index formed from the breadth at the level of the deltoid tubercle and the total length of the bone. It is not quite clear whether all authors have taken the breadth at exactly the same place, but accepting their values we obtain Table 7.

There are five skeletons with both right and left humerus; in one (Cap-Blanc) the difference between the two sides is so small as to fall probably within the errors of measuring, in the other four, it is larger than the standard deviation of the whole series, twice in favor of the right, twice of the left side. It is probably rash to draw any conclusions as to right- or left-handedness, but it may be pointed out that according to Elliot Smith the anatomical preponderance at least of one hemisphere of the brain is less pronounced in primitive than in higher races.

In order to compare the stoutness of the humerus of the Upper Palaeolithic and other races, we shall have to make use of the "index of robusticity," expressing the least circumference in percentages of the maximum length, for this is the only measurement available for the Neolithic people. The data which could be found have been assembled in Table 7. There are only a few entries, but the mean of the Upper Palaeolithics (19.3) suggests that this index was smaller among them than among subsequent populations of France.

Some of the indices and angles of radius and ulna may be compared with the values given by Eugen Fischer ('06) in his famous monograph

* These are the usual biometric notations; for explanation see Table 1.

TABLE 7

Indices of Humerus of Upper Palaeolithic Skeletons

BREADTH INDEX

Grotte des Enfants	R	7.3
	L	6.3
Barma Grande I	R	8.8
	L	6.9
Barma Grande II	R	5.7
	L	8.3
Cro-Magnon		6.0
Combe Capelle		7.3
Obercassel ♀		6.8
Obercassel ♂	R	7.2
	L	8.0
Grimaldi		6.5
Cap-Blanc	R	7.1
	L	7.2
Mean		7.1
Standard deviation		0.66

INDEX OF ROBUSTICITY

Obercassel ♂		19.3
Obercassel ♀		19.8
Cap-Blanc ♀	R	19.4
	L	18.7
Cro-Magnon ♂		18.7
Combe Capelle ♂		20.1

	♂	♀
Les Mureaux	20.5 (10)	17.6 (5)
Grotte des Fées	21.0 (19)	20.0 (8)
Châlons-sur-Marne	20.1 (17)	20.0 (15)
Chamblandes	20.2 (10)	20.0 (13) *

* All these figures from French Neolithics are indices of means.

on these bones. While the radius of the Cap-Blanc skeleton is quite stout, judged by its index of robusticity, the ulna is rather slender, just as that of Africans and South Sea Islanders. The evidence from the collo-diaphyseal angle of the radius is inconclusive, the high value of the Obercassel specimen clearly indicating that we cannot place too much confidence on the Cap-Blanc radius alone. The curvature of the radius is high in three of the four radii at hand, thus siding rather with the Europeans than with the "primitive" races. The configuration of the articular surface of the olecranon of the ulna as described by the indices 7/6 and 8/6 (cf. Table 1) is again inconclusive, but the two values of the index 7/6 tabulated first indicate a resemblance to Europeans, while the index 8/6, being nearly the same in both the Obercassel and the Cap-Blanc skeletons, points rather to a resemblance to "Africans." The configuration of the facet on the coronoid process is peculiar, the mean of the index 9/10 being higher than in any of the three races with which it is compared here. Again, there is no clear cut evidence pointing to a closer relation between the Upper Palaeolithic and any one modern race.

We can put the measurements made on the skeleton of the hand to some use by basing our analysis on the extensive investigations recently published by Sarasin ('31). This memoir contains numerous measurements mostly given for series of mixed sex, and an attempt has

TABLE 8

Comparative Figures for Radius and Ulna

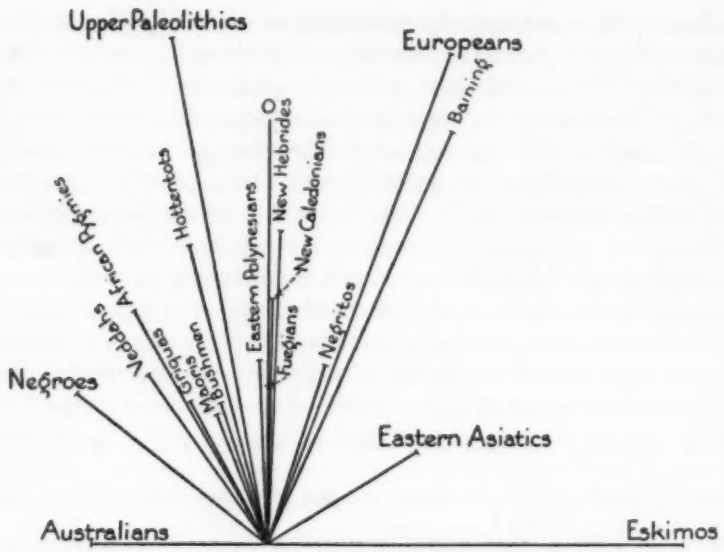
RADIUS	CAP-BLANC R	CAP-BLANC L	OBERCASSEL * R	OBERCASSEL * L	EUROPEANS †	AFRICA †	OCEANIA †
Index of robusticity ...	18.0	17.5	...	...	18.1 (25)	16.7 (7)	15.7 (18)
Collo-diaphyseal angle ..	167°	164°	...	174°	171°.6 (25)	169°.7 (12)	165°.4 (34)
Curvature	4.1	3.3	3.7	2.1	3.2 (25)	...	3.0 (18)
ULNA			♂	♀			
Index of robusticity 3/2		13.4	14.7	16.8	16.8 (25)	13.5 (8)	13.4 (19)
Index 7/6	89.6		89.3	104.3	98 (25)	92 (11)	102.5 (24)
Index 8/6	83.3		82.2	82.6	80 (25)	83 (11)	86 (24)
Index 9/10	80.2?		85.7	71.4	72 (25)	65 (6)	53 (24)
(cf Table 1.)							

* After Bonnet. † After Fischer.

there been made to evaluate the racial differences by applying Mollison's method of *"Typen Differenz"* which leads to those diagrams of broken lines with which many German anthropological papers abound. But it is hard, at least for us, to visualize Sarasin's results in this way. We have preferred to try out once more a method of analysis developed some time ago by Pearson and Bell ('19) and applied by them to the femur. The method is briefly this: from data of the intraracial means of a number of characters the interracial means and standard deviations are computed, and for each character of each race its distance from the mean expressed in terms of the standard deviation is determined. We can then find for each race mean distances from the means, once having no regard to the sign of the deviation (expressed by the symbol $m\ (|n|)$) and once having regard to sign (expressed by the symbol $m\ (n)$). The quotient $\frac{m\ (n)}{m\ (|n|)}$ will take any value between $+1$ and -1. Putting $r = m\ (n)$, and $\frac{m\ (n)}{m\ (|n|)} = \sin\theta$, we can plot the place of each race in a polar coördinate diagram conveniently with the positive direction of the axis running upwards and the positive value of θ on the right side.

This analysis is based on interracial means and standard deviations; thus an approximately "normal" distribution of the variants within the considered universe of races is assumed. That may be considered legitimate (although it has not been proven) when dealing with races of one species, but becomes a bold and probably dangerous simplification when several species or even genera are involved.

From Sarasin's data seven indices have been selected, and r and $\sin\theta$ computed for each race. Only when these computations had been made were the rather uncertain means for the Upper Palaeolithics added. The diagram obtained is given in Figure 1. Its results are interesting in several respects. Most of the races are grouped fairly closely together, between the Europeans on the one and the Negroes on the other side. Far away are the Eskimos and the Australians, the Eastern Asiatics showing a somewhat aberrant type, too. Disregarding for the moment the Baining, who are known from only a very small sample (4 or 5 skeletons), the Europeans are farther removed from the mean than any other type, while the Fuegians hold an almost central position. The Upper Palaeolithics are almost as far removed from the interracial mean as the Europeans, but they are about equally distant from the Negroes and from the Europeans and very far from the Eskimos. The information about the



Relationships of races based on indices of hand skeleton, mainly after Sarasin's measurements.

FIG. 1

fossil race is too incomplete to draw any positive conclusions, but it does not support any theory which places it near a particular modern race. Such relationships have to be proven from other data.

Coming to the lower extremity, the homogeneity of the Upper Palaeolithic people can be tested by the platymeric and the platycnemic indices, both of which have been given for most skeletons (Table 9). The measurements for the platymeric index should be taken at the level of the least antero-posterior diameter in the infratrochanteric region, those for the platycnemic index at the height of the foramen nutritium of the tibia. Since most skeletons have been measured by French authors, it is reasonably sure that these at least have been investigated in the manner just described. As to the specimens from Combe Capelle and Obercassel, the platymeric index has been taken from Pearson and Bell ('19) in the first instance, whereas both Klaatsch ('10) and Bonnet ('19) have given the platycnemic diameters from which this index was checked by us. It will be noticed that Bonnet's value of the index has been changed. Since we are at present mainly concerned with the variability, we note at once that the standard deviation of the platymeric index is $7.59 \pm .93$, as compared with $8.765 \pm .272$ for

the London femora measured by Pearson and Bell ('19), and that the standard deviation for the platycnemic index is 4.97±.59 as compared with 4.1±.3 obtained by Davidson Black ('25) on a mixed series of northern Chinese. Neither of these values differs significantly from that with which it is compared; thus the study of these two characters shows again no reason for cutting up the Upper Palaeolithic people into various racial groups.

TABLE 9

Indices of Femur and Tibia

	PLATY-MERIC INDEX	PILASTRIC INDEX	PLATY-CNEMIC INDEX
Cro-Magnon	84.7	125.2	68.5
Grotte des Enfants	R 77	....	70.2
	L 76	....	67.4
Barma Grande I	R 69	....	58.3
	L 75	....	59.6
Barma Grande II	R 54	....	61.5
	L 67 ?	....	61.7
Musée de Menton	76	....	...
Obercassel ♂	R 69.8	....	61.9
	L 77.5 ?	109.4	55.6
Obercassel ♀	R 78.1 ?	100	...
Grimaldi	81.8	....	68.4
Grotte du Cavillon	...	....	65.1
Lautsch	70.6	121.7	...
Chancelade	...	110.9	64.0 ?
Combe Capelle	86.4	114.0	58.3
	...	....	67.6
Cap-Blanc	R 76.1	121.7	70.8
	L 73.4	125.1	70.4
Mean	74.5 (16)	116.0 (8)	64.4 (16)
Dolmen d'Épône	76.1 (47)	110.1 (26)	63.5 (21)
Châlons-sur-Marne	75.0 (33)	108.5 (33)	62.7 (41)
Montigny-Esbly	77.4 (24)	111.3 (24)	65.2 (95)
Les Mureaux	78.3 (16)	106.1 (16)	63.7 (18)
Grotte des Fées	73.5 (67)	107.4 (47)	62.2(128)
Chamblandes	72.1 (37)	105.1 (38)	65.1 (41)

We can compare these results with those obtained on some groups of French Neolithic skeletons also given in Table 9. Comparing the mean platymeric and platycnemic index of the Upper Palaeolithic with the various Neolithic groups, there are no significant differences, as can be easily verified. (It should not be overlooked, on the other hand, that there are significant differences between some of the Neolithic series, e.g. in the platycnemic index of Montigny-Esbly and of the Grotte des Fées.) While these two characters furnish evidence that the Upper Palaeolithic and Neolithic types are racially related, it is not certain how far the pilastric index corroborates this conclusion. Based, it is true, on an insufficient number of observations (8), it is rather greater in the Palaeolithic series (116.0) than in the later ones, but the significance of these numbers is not clear.

On the other hand, the configuration of the fibula appears to be well in line with platymery and platycnemy. The shaft of that bone is

TABLE 10

Comparative Data of Indices and Angles of Talus, After Szombathy and Poniatowsky

	CAP-BLANC *	LAUTSCH (S)	TIROLESE (P)	ALAMANS (P)	BURMESE (P)
breadth index	81.6	86.7	80.5	81.0	77.8
height index	59.4	66.4	59.25	58.8	57.8
trochlea-talus length index	63.75	69.0	65.4	65.35	63.75
trochlea-talus breadth index	68.6	71.4	69.25	69.05	68.1
trochlear breadth index	87.95	89.7	85.9	86.95	83.5
lateral malleolar facet-talus breadth index	66.3	...	58.0	56.2	63.8
posterior facet index	70.2	72.2	69.0	70.1	67.4
caput index	59.8	...	64.2	64.6	64.1
caput-talus index	65.15	...	61.8	62.4	59.6
angle of facies artic. post	42°.8	40°	41°.4	39°.6	45°.5
angle of collum tali	32°.6	6°	23°.7	20°.8	20°.5
angle of torsion of caput	21°.2	...	35°.25	39°.3	36°.7

* Mean of both sides.

consistently described as deeply fluted among the Upper Palaeolithic skeletons, and the same terms are used for the Neolithic ones.

Only a few intact bones of the foot have been found thus far, and it is therefore impossible at present to arrive at more than preliminary hypotheses.

Of the talus, we have, except for the Cap-Blanc specimen, one from Chancelade, those from the Grotte des Enfants (from the Cro-Magnon as well as from the Negroid specimens), those from the two skeletons from Barma Grande and one bone from Lautsch, regarding which Szombathy ('25) came to the conclusion "dass mit ihm zunächst nichts anzufangen ist." Unfortunately the French finds have not been measured as fully as one might wish for. They were all found before the modern methods of measurements had been developed by Volkov ('03-'04) and Poniatowsky ('14), and we are therefore thrown back on the Cap-Blanc and Lautsch specimens. Their indices and angles are compared in Table 10 with some figures taken from Poniatowsky's paper based unfortunately in some instances on but six observations. Regarding the indices, both Upper Palaeolithic specimens exhibit a tendency to side with the "higher" races, the tali are broad and high and have a comparatively long trochlea. When we come to the angle of the collum, the evidence is conflicting. While Szombathy measured an unusually small angle, we found unusually large ones in the Cap-Blanc tali.[2] Measuring of angles is frequently difficult, and the personal error may be expected to be large (Poniatowsky estimates it at at least 1.5 degrees), but even this would not do away with the discrepancy just noted. For the moment we have to admit that we do not know how this angle behaved in our fossil race, but this is perhaps less serious than it looks at first sight. None of the differences in Poniatowsky's table are significant, and it appears, therefore, to be of doubtful value for racial characterization. It should be emphasized, moreover, that it has not yet been proven that the deviation of the head of the human astragalus is closely correlated with the deviation of the hallux, although both Volkov and Poniatowsky appear to believe this.

[2] Poniatowsky's lowest value for the mean of a human race is 20°.5, and the standard deviation for his longest series is 3.55. Szombathy's value is 6°. Taking 20 as a round figure, the Lautsch specimen would be 3.94 removed from the lowest racial mean. However, the lowest individual value found by Poniatowsky was 8° for an Australian male (No. 3656).

A discussion of the calcaneus is rendered difficult—apart from the scarcity of material—by the fact that various authors have used, in many instances, measurements that are not comparable.

Means and standard deviations for "Europeans" were computed from the "Alemannen," "Tiroler" and "Schweizer" measured by Reicher ('13). The means for the various series were weighted by the number of cases on which they were computed, the standard deviations by the square root of these numbers. The resulting values are given in columns 3 and 4 respectively of Table 11. The last columns express

TABLE 11

Indices of Calcaneus of Cap-Blanc, Compared With Those of Europeans, After Reicher (see text)

DESIGNATION OF INDICES	CAP-BLANC		EUROPEANS			
	R	L	Means	σ	Δ_R	Δ_L
length breadth index ...	52.5	55.3	53.7 (62)	3.43	— .35	+ .47
length height index	52.3	51.9	50.8 (52)	3.13	+ .48	+ .35
corpus length index ...	65.6	67.7	72.4 (63)	2.31	—2.94	—2.03
first tuber index	70.0	65.4?	63.5 (50)	3.99	+1.63	+ .48
index of posterior facet	83.0	81.9	73.7 (60)	5.73	+1.62	+1.43
index of cuboidal facet	100 ?	100 ?	78.1 (53)	9.91	+2.21	+2.21
second tuber index	53.2	52.5	59.3 (57)	3.32	—1.84	—2.05

the differences between these means and the right and left Cap-Blanc calcaneus in terms of their standard deviations. In most instances the difference is so small as to make it probable that the Cap-Blanc specimens were not significantly different from the European series. Only the corpus length index, the index of the cuboidal facet, and the second tuber index are suspicious. The index of the cuboidal facet, however, is of doubtful accuracy and hence may be disregarded. All that remains is that the Cap-Blanc calcaneus appears to have a shorter and lower "heel" than Europeans. The values given for the Obercassel skeleton disturb the clear cut lines of this picture. There, the second tuber index is as exceptionally high as it was low in the Cap-Blanc skeleton. On the other hand, the Obercassel man, too, had a remarkably short heel. But even here we are not sure whether we are confronted with a racial character in the ordinary sense of the word. Verneau ('06) and Testut

('89) have determined the length of the heel in the skeletons described by them. They have both measured in the same way, differing, however, from the technique employed by later authors. From their values we should conclude that at least the skeletons from the Caves of Grimaldi had an unusually long heel, but that the Chancelade skeleton falls in with the Cap-Blanc and Obercassel specimens. While the mean corpus length index would probably still be lower than in Europeans, it is doubtful whether a significant difference will be found on the basis of the material at present available, but so long as we do not have uniform measurements no definite conclusions can be arrived at.

Reicher's talo-calcaneus angle, defined as the angle which the long axis of the calcaneus forms with the long axis of the trochlea tali and determined by subtracting the angle of the posterior facet on the talus from that angle on the calcaneus, is known only for the Cap-Blanc. We find 12°.2 as the mean of both sides of the Cap-Blanc skeleton, a value as large as any found hitherto, but clearly within the range of variability of modern man.

We do not propose to discuss the other tarsal bones in detail since very little comparative material is available, but shall only give a few remarks on the metatarsals, particularly the first one.

It is customary to form an index out of the length of the first metatarsal, and the sum of the length of the tibia (l) and the oblique length of the femur (d), in order to give some indication as to the relative size of the foot. We obtain the figures of Table 12.

TABLE 12

Index of First Metatarsal and Long Bones of Leg

Cap-Blanc	R	7.47
	L	7.67
Grotte des Enfants		7.52
Barma Grande I		7.51
Modern man	♂ *	7.01
	♀ *	7.2

* After Volkov. Weighted means of his Table CVII.

SURVIVAL OF UPPER PALAEOLITHICS

This is not the place to discuss in detail the bearing of craniological evidence on the question of the survival of the Upper Palaeolithic race.

Moreover, pertinent figures have already been given by Morant. Yet a few facts may be pointed out which, it is hoped, will throw some further light on this problem. We would wish, in the first place, to re-emphasize a Neolithic series from Beaumes-Chaudes which, mentioned frequently and prominently in the French literature toward the end of the last century, appears to have been forgotten more and more as time went on. Measured by Broca, the means of this series were first published by Topinard ('86), and later a photograph of one skull by Mayet ('12). The skulls had been found by Prunières in an almost inaccessible cave in the upper valley of the Tarn.

Topinard concluded from this location that very likely Prunières had found the last descendants of an older, probably Palaeolithic population. But by a curious twist of thought, he claimed that their ancestors were not the "Cro-Magnon," but another unknown race which, he trusted, the future would bring to light. Other authors have apparently not followed Topinard here, but accepted the resemblance between the Cro-Magnon and the Beaumes-Chaudes race, and even speak of a "race of Cro-Magnon—Beaumes-Chaudes."

It is of interest to put together the means of the Upper Palaeolithics, the Beaumes-Chaudes, the British Neolithics,[3] the Norwegian Iron Age[4] and the Anglo-Saxons,[3] the last three of which no anthropologist would hesitate to call "Nordic." An inspection of Table 14 will show that the Beaumes-Chaudes take up an intermediate position in many instances. We can, however, analyze this still further, and compute the Coefficients of Racial Likeness between these races. Unfortunately, the zygomatic breadth is the only facial character of the Beaumes-Chaudes series available for this work, and it is the only one which shows a significant difference from the Upper Palaeolithic. There may, therefore, be other differentiating characters in the face. At any rate, we can assert that the brain-box of the two races showed (on the basis of our present samples) only insignificant differences, a result which strongly supports Hervé's ('94) conceptions of the relation of these two races. What, on the other side, is the relation between the Beaumes-Chaudes series and the three "Nordic" races? There are close connections throughout, so close in fact that one would be justified in calling the Beaumes-Chaudes, too, a "Nordic" race.

Summing up the content of Table 14, there is a strong indication that the "Cro-Magnon" race went into the makeup of the Nordics. Originating in all probability from a cross between the descendants of

[3] G. M. Morant '26.
[4] Schreiner, '27.

TABLE 13

Means for Male Skulls for Upper Palaeolithics, French Neolithics From Beaumes Chaudes and Some "Nordic" Races

	UPPER PALAEOLITHICS		BEAUMES CHAUDES		NORWEGIAN IRON AGE		BRITISH NEOLITHICS		ANGLO-SAXONS	
L	198.1	20	194.95	21	194.3	26	193.7	53	190.6	58
B	142.2	18	141	21	138.6	25	138.9	128	141.7	103
H'	135.8	9	140	13	136.7	21	135.5	25	136.0	31
B'	98.6	24	98.6	18	96.6	25	98.7	41	97.3	59
LB	104.8	9	104.3	12	106.8	21	103.3	21	104.1	31
fml	40.8	8	37	11	37.5	20	36.3	17	37.5	20
fmb	31.0	8	31.2	11	31.1	20	30.4	7	31.1	18
S	394.5	14	396.4	14	383.7	24	389.0	31	379.8	64
U	549.1	14	541.7	16	534.5	24	536.6	106	532.0	73
Q'	330.3	9	.....		.....		.....		316.1	23
BQ'	329.1	9	.....		314.8	24	308.5	10	.....	
G'H	71.4	11	78.25	?	72.8	13	70.8	32	71.7	22
GL	101.4	6	.....		.....		.....		96.0	22
GB	103.3	7	.....		.....		95.3	11	95.0	19
J	142.8	9	132.5	11	139.0	8	130.4	41	133.3	34
O_1R	44.8	12	.....		42.8	17	.....		42.9	19
$O_1'R$	41.1	4	.....		.....		.....		.....	
O_2R	31.3	11	33.4	4	33.9	17	32.6	27	33.6	29
NHL	52.9	12	.....		51.5	15	50.6	15	52.3	22
NH'	52.7	13	56.75	?	.....		.....		.....	
NB	25.9	14	23.	?	24.8	13	23.6	34	24.5	28
G_1'	47.6	4	.....		47.4	13	46.1	21	46.1	21
G_1	53.8	4	.....		.....		.....		.....	
G_2	40.6	11	35	4?	41.3	12	40.2	7	41.3	27
G''	56.9	4	.....		.....		.....		.....	
EH	14.7	6	.....		.....		.....		12.4	16
Indices										
100 B/L	72.6	18	72.3	21	71.3	25	71.1	48	74.7	52
100 H'/L	69.4	8	72.3	13	70.7	21	69.4	21	71.2	25
100 G'H/GB	70.8	7	.....		76.7	10	75.2	10	75.3	43
100 NB/NHL	49.6	11	.....		.....		.....		47.9	19
100 NB/NH'	49.8	11	40.5	?	47.9	13	46.5	13	47.5	58
100 O_2/O_1R	69.5	11	.....		79.5	16	76.8	3	77.9	19
100 fmb/fml	76.7	7	84.3	11	83.1	20	83.7	5	82.3	18
100 G_2/G_1	75.4	4	.....		.....		.....		81.5	18
Oc.I	57.9	13	.....		57.9	24	.....		58.2	35
100 B/H'	103.9	8	.....		100.7	21	102.4	23	104.9	61
PP∠	.....		.....		84°.0	14	.....		.....	
P∠	88°.5	11	.....		.....		83°.3	4	88°.1	16

TABLE 14

Coefficients of Racial Likeness Between the Races Given in Table 13

	UPPER PALAEOLITHICS	BEAUMES CHAUDES	NORWEGIAN IRON AGE	BRITISH NEOLITHICS	ANGLO-SAXONS
Upper Palaeolithics	.....	2.65± .24	2.89± .18	4.18± .18	5.08± .18
Beaumes Chaudes	19.67±1.78	.....	.61± .24	.98± .25	1.57± .24
Norwegian Iron Age	19.11±1.20	3.37±1.33	.....	.58± .22	1.31± .20
British Neolithics	30.13±1.03	4.40±1.12	2.22± .84	.....	2.73± .18
Anglo-Saxons	33.71±1.02	6.98±1.07	8.06± .79	8.29± .55	.....

Upper right: crude coefficients.
Lower left: reduced coefficients.

the Upper Palaeolithics and a Neolithic race, the cradle of the Nordics would according to this view be in Western Europe. During Neolithic times, they appear to have been driven or migrated into its remotest corner, England, and later (after the advent of the superior brachycephalic British Bronze Age peoples?) to have drifted into Northern Europe. Gradually they seem to have advanced in cultural abilities, and they eventually reappeared on the scene in England (as Anglo-Saxons), at the same time spreading over that part of Europe which is now Germany and France. That in these regions the type of the population has changed during historic times, is a matter of common knowledge.

Our investigations have not advanced far enough, and we are therefore not yet prepared to say definitely whether the Nordics are the result of a racial mixture between the Cro-Magnons and one (or several) of the races which entered France (or Europe) in Neolithic times, nor can we account for the wanderings and the distribution of the Nordic races throughout their existence. A re-examination of the whole French Neolithic material is needed in the first place, but this

obviously can not be done in Chicago. To point out, however, the lines along which further research appears to be most promising, seemed to us appropriate.

SUMMARY

We can confirm the result reached by G. M. Morant on a purely craniological basis, that the Upper Palaeolithics are racially homogeneous.

In support of this view we have found that stature, platymeric and platycnemic index show a variability essentially the same as that of modern samples supposedly from homogeneous races. On the other hand, we have found that the proportions of the long bones and the sex ratio of the stature are different from modern races, but in both cases there is reason to mistrust our data.

This race was of tall stature (above 170 cm. for males); it had a large skull such as was described in detail a few years ago by Morant; its upper extremities resembled those of modern primitive races; its lower extremities were perhaps less stable in the proportion of thigh and leg than in modern races; it had a platymeric and pronouncedly pilastric femur, a platycnemic tibia, and a deeply fluted fibula.

It is impossible to make any general statements about the skeleton of the feet in view of the insufficient data so far published, but there are indications that the foot of the Upper Palaeolithics differed in some respects from those of modern races.

There are good reasons to assume that descendants of this type survived in Neolithic times: Platymery, platycnemy and a deeply fluted fibula still persist, and there is at least one series (from Beaumes-Chaudes) resembling the Upper Palaeolithics on the one hand and some primitive Nordics on the other hand very closely in the size and shape of their skulls.

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Abbreviations.— *Arch. Anthrop. N. F.=Archiv für Anthropologie, Neue Folge. Biom.=Biometrika. B. S. A. L.=Bulletin de la Société d'Anthropologie de Lyons. B. S. A. P.=Bulletin de la Société d'Anthropologie de Paris. Z. Morph. u. Anthropol.=Zeitschrift für Morphologie und Anthropologie.*

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HEREDITY OF THE AGGLUTINOGENS M AND N OF LANDSTEINER AND LEVINE.

IV. ADDITIONAL THEORETICO-STATISTICAL CONSIDERATIONS*

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IN PRECEDING articles (4, 5, 6) evidence was presented that confirmed the theory formulated by Landsteiner and Levine (1, 2, 3) that the agglutinogens M and N of human blood are inherited by means of a single pair of allelomorphic genes. The accuracy of this theory has also been confirmed by the investigations of a number of other independent workers (7-15). According to the theory of Landsteiner and Levine, only three genotypes are possible, namely, genotypes MM, MN, and NN, corresponding to the phenotypes, type M or M + N — (blood containing agglutinogen M, but not agglutinogen N), type MN or M + N + (blood containing both agglutinogens, M and N), and type N or M—N+ (blood containing only agglutinogen N). The theory therefore accounts for the non-existence of bloods lacking both agglutinogens.

In the preceding papers of this series, three different methods of study were employed, namely, (a) the analysis of complete families, each member of which had been tested for M and N, (b) the comparison of the M/N types of mothers and children, and (c) the determination of the distribution of the agglutinogens M and N in different populations. The major portion of the present paper will be devoted to an analysis of information that can be obtained from statistics described under heading (c). Part of this will be a repetition and an elaboration of theoretico-statistical considerations previously presented.

PART I. THE RELATION $m + n = 1$

Let us consider a population which is at equilibrium with respect to the agglutinogens M and N. It has been demonstrated that the distri-

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bution of the types M, N, and MN becomes constant after only a single generation of random intermarriage (5).

If we designate the frequencies of the genes M and N by m and n, respectively, then $m + n = 1$. The frequencies of the three phenotypes in terms of the frequencies of the genes are then derived as follows:

Phenotype	*Genotype*	*Frequency*	
M	MM	m^2	(1)
N	NN	n^2	(2)
MN	MN	$2mn$	(3)

So that, $m = \sqrt{\overline{\mathrm{M}}}$ (4)

$n = \sqrt{\overline{\mathrm{N}}}$ (5)

And $\sqrt{\overline{\mathrm{M}}} + \sqrt{\overline{\mathrm{N}}} = 1$ (6)

where $\overline{\mathrm{M}}$ and $\overline{\mathrm{N}}$ represent the frequencies of types M and N, respectively.

Since it is impracticable to examine every individual in the population, one cannot determine the exact value of $\overline{\mathrm{M}}$ and $\overline{\mathrm{N}}$, but must deduce its value from the distribution of the M/N types in a sample. With the observed frequencies, relation (6) will not hold exactly, but it is to be expected that if the theory is correct, the larger the sample examined, the closer will the relation hold. To determine whether or not the sum $\sqrt{\overline{\mathrm{M}}} + \sqrt{\overline{\mathrm{N}}}$ differs significantly from unity, it is necessary to calculate the standard error of this sum.[1]

If we represent the *true* frequencies of types M, N, and MN, by R, S, and T, respectively, and the corresponding frequencies in the sample examined by R', S', and T',

Then, $R' = R + x$ (7)

$S' = S + y$ (8)

$T' = T + z$ (9)

By taking U different samples (where U represents a large number), each containing the same number of individuals (V), one can determine

[1] For convenience, in this paper only the standard error will be used. To convert standard error into probable error, it is only necessary to multiply by the factor 0.6745.

the standard error of the observed frequency R, for example, for a sample of the given size, as follows:

$$\sigma_R = \lim_{U \to \infty} \sqrt{\frac{\Sigma x^2}{U}} \tag{10}$$

The standard error of an observed frequency p is known to be equal to $\sqrt{\frac{p(1-p)}{V}}$, where V represents the number of individuals in the sample examined.[2]

$$\text{Therefore, } \sigma_R = \sqrt{\frac{R(1-R)}{V}} \tag{11}$$

If we represent $\lim_{U \to \infty} \left(\frac{\Sigma x^2}{U} \right)$ by $f(x^2)$,

$$\text{then, } f(x^2) = \sigma_R{}^2 = \frac{R(1-R)}{V} \tag{12}$$

$$\text{Similarly, } f(y^2) = \sigma_S{}^2 = \frac{S(1-S)}{V} \tag{13}$$

$$\text{and} \quad f(z^2) = \sigma_T{}^2 = \frac{T(1-T)}{V} \tag{14}$$

If, now, we let m and n represent the *true* frequencies of genes M and N, respectively, and m' and n' the corresponding calculated frequencies, from (1) and (2), it follows that

$$R = m^2$$
$$S = n^2$$
$$R' = m'^2$$
$$S' = n'^2$$

$$\text{Therefore, } m' = \sqrt{R'} = \sqrt{R + x} = \sqrt{R} + \frac{x}{2\sqrt{R}} \tag{15}$$

$$n' = \sqrt{S'} = \sqrt{S + y} = \sqrt{S} + \frac{y}{2\sqrt{S}} \tag{16}$$

(neglecting terms containing x and y to the second and higher powers),

$$\text{Or} \qquad m' = m + \frac{x}{2\sqrt{R}} \tag{17}$$

$$n' = n + \frac{y}{2\sqrt{S}} \tag{18}$$

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[2] The derivation of this formula is given in Kelley's *Statistical Method*, page 89, New York (1924). Also see Yule's *Introduction to the Theory of Statistics*, page 256, London (1927).

If we now set $D = 1 - (m' + n')$ (19)

$\sigma_D^2 = f[1 - (m' + n')]^2 = f[(m' - m) + (n' - n)]^2$ (20)

$$\sigma_D^2 = f\left[\frac{x^2}{4R} + \frac{xy}{2\sqrt{RS}} + \frac{y^2}{4S}\right] = \frac{1}{4R} f(x^2) + \frac{1}{2\sqrt{RS}} f(xy) + \frac{1}{4S} f(y^2)$$

The values of $f(x^2)$ and $f(y^2)$ are given in (12) and (13), so that it is only necessary to determine the value of $f(xy)$. From the definition of the correlation coefficient,

$$r_{RS} = \frac{f(xy)}{\sqrt{f(x^2)} \cdot \sqrt{f(y^2)}} \tag{21}$$

so that it is necessary to derive the value of r_{RS}. This is done as follows:

Let $\bar{y}$ be an estimated deviation of the observed frequency S' from S, corresponding to a deviation x of R' from R.

Then, $\bar{y} = -x \dfrac{S}{1 - R}$

$$b_{SR} = -x \frac{S}{1 - R} \div x = -\frac{S}{1 - R}$$

where b_{SR} is the regression coefficient of S on R.

Similarly, $b_{RS} = -\dfrac{R}{1 - S}$

Since $r_{RS} = \sqrt{b_{RS} \cdot b_{SR}}$

(from one of the definitions of the coefficient of correlation)

Therefore, $r_{RS} = -\sqrt{\dfrac{RS}{(1 - R)(1 - S)}}$ (22)

$f(xy) = r_{RS} \sqrt{f(x^2)} \sqrt{f(y^2)}$

or $f(xy) = -\dfrac{RS}{V}$ (23)

Hence, $\sigma_D^2 = \dfrac{1}{4R} \cdot \dfrac{R(1 - R)}{V} - \dfrac{1}{2\sqrt{RS}} \cdot \dfrac{RS}{V} + \dfrac{1}{4S} \cdot \dfrac{S(1 - S)}{V}$

Setting $R = m^2$ and $S = n^2$, we have

$$\sigma_D^2 = \frac{2 - m^2 - 2mn - n^2}{4V} = \frac{2 - (m + n)^2}{4V} = \frac{1}{4V}$$

So that, $\sigma_D = \dfrac{1}{2\sqrt{V}}$ (24)

TABLE 1

Comparison of the Difference, $(m+n) - 1$, and Its Standard Error

INVESTIGATOR	NUMBER OF INDIVIDUALS EXAMINED	$m+n$	D± STANDARD ERROR
Landsteiner-Levine			
Whites (New York)	532	96.18	3.82±2.18
Colored	181	102.46	2.46±3.72
American Indians	205	99.55	0.45±3.49
Wiener-Vaisberg	904	101.34	1.34±1.66
Wiener, Rothberg, Fox			
Mothers	461	99.39	0.61±2.33
Children	497	98.70	1.30±2.24
Schiff			
Berlin	3333	99.92	0.08±0.87
Wolgadeutsche	180	101.02	1.02±3.73
Shigeno			
Japanese	202	103.94	3.94±3.52
Blaurock			
Cologne	2000	100.31	0.31±1.12
Thomsen-Clausen			
Copenhagen	442	105.20	5.20±2.43
Lattes-Garrasi			
Italians	430	91.27	8.73±2.41
Kossovitch			
French	400	103.49	3.49±2.50
Laubenheimer			
Frankfort a. M.	1000	96.82	3.18±1.58
Wolff *			
Stockholm	410	101.0	1.0 ±2.47
Wagner *			
Danzig	1500	98.23	1.77±1.29

* Cited after Schiff, *Deutsche Zeitschr. f. d. ges. gerichtl. Med.*, 1933, 21, 404.

In Table 1 are listed several populations collected from the literature, for which have been calculated the value of the sum, $m + n$, and its standard error, according to formula (24). With but one exception (Lattes-Garrasi), the deviation from 100 per cent is not significantly greater than the standard error. In this case the discrepancy could possibly be explained by assuming that the testing fluids used were insufficiently absorbed.

PART II. APPLICATION OF THE METHOD OF MAXIMUM LIKELIHOOD TO THE STUDY OF THE HEREDITY OF THE AGGLUTINOGENS M AND N

Dr. R. A. Fisher, of the Rothamsted Experimental Station, in a personal communication, has suggested the application of the χ^2-test to the theory of Landsteiner and Levine. The maximum likelihood estimate of the frequencies of the genes M and N is derived as follows:

As in the previous section, let R, S, and T represent the *true* percentage frequencies of types M, N, and MN, in the population. The chance that in a given sample of V individuals, there will be a individuals of type M, b of type MN, and c of type N is given by

$$W = \frac{\lfloor V}{\lfloor a \lfloor b \lfloor c} R^a S^c T^b$$

where, $a + b + c = V$

Or, since $R = m^2$, $S = n^2$, and $T = 2mn$,

$$W = \frac{\lfloor V}{\lfloor a \lfloor b \lfloor c} (m^2)^a (n^2)^c (2mn)^b \tag{25}$$

$$\log W = \log \frac{\lfloor V}{\lfloor a \lfloor b \lfloor c} + a \log m^2 + c \log n^2 + b \log 2mn$$

Since $m + n = 1$,

$$\frac{d \log W}{dm} = \frac{a}{m^2} \cdot 2m - \frac{c}{(1-m)^2}[2(1-m)] + \frac{b}{2m(1-m)}(2-4m)$$

The value of m that gives the best fit is one that makes W a maximum, so that we set $\frac{d \log W}{dm} = 0$.

Hence, $$\frac{2a}{m} - \frac{2c}{1-m} + \frac{b(1-2m)}{m(1-m)} = 0$$

$$2a(1-m) - 2cm + b(1-2m) = 0$$

$$2a + b - 2m(a + b + c) = 0$$

$$2mV = 2a + b$$

$$m = \frac{2a + b}{2V} \tag{26}$$

Similarly,
$$n = \frac{b + 2c}{2V} \tag{27}$$

$$\chi^2 = \frac{\Sigma(x - x_0)^2}{x_0} = \frac{(a - a_0)^2}{a_0} + \frac{(b - b_0)^2}{b_0} + \frac{(c - c_0)^2}{c_0}$$

$$a_0 = Vm^2 = V\left(\frac{2a + b}{2V}\right)^2$$

$$a - a_0 = a - \frac{(2a + b)^2}{4V} = \frac{4aV - (2a + b)^2}{4V} =$$

$$\frac{4a(a + b + c) - (2a + b)^2}{4V}$$

$$a - a_0 = \frac{4ac - b^2}{4V}$$

$$\frac{(a - a_0)^2}{a_0} = \frac{(b^2 - 4ac)^2}{4V(2a + b)^2}$$

Similarly, $\frac{(c - c_0)^2}{c_0} = \frac{(b^2 - 4ac)^2}{4V(b + 2c)^2}$

and $\frac{(b - b_0)^2}{b_0} = \frac{(b^2 - 4ac)^2}{2V(2a + b)\ (b + 2c)}$

$$\chi^2 = \frac{(b^2 - 4ac)^2\ [(b + 2c)^2 + 2(2a + b)\ (b + 2c) + (2a + b)^2]}{4V(2a + b)^2\ (b + 2c)^2}$$

$$\chi^2 = \frac{(b^2 - 4ac)^2\ (2a + 2b + 2c)^2}{4V(2a + b)^2\ (b + 2c)^2}$$

$$\chi^2 = \frac{(b^2 - 4ac)^2 V}{(2a + b)^2\ (b + 2c)^2} \tag{28}[3]$$

Since $R = \frac{a}{V}$, $S = \frac{c}{V}$, $T = \frac{b}{V}$,

$$\chi^2 = \frac{(T^2 - 4RS)^2 V}{(2R + T)^2\ (2S + T)^2} \tag{29}$$

[3] This formula was originally derived by Fisher (personal communication).

TABLE 2

χ^2 Test of the Theory of Landsteiner and Levine

INVESTIGATOR	FREQUENCY OF TYPE			NUMBER OF INDIVIDUALS EXAMINED	χ^2	P
	MN	M	N			
Landsteiner-Levine						
Whites (New York)	53.6	26.1	20.3	532	3.04	0.08
Colored	47.5	27.6	24.9	181	0.35	0.55
American Indians	35.12	60.00	4.88	205	0.021	0.89
Wiener-Vaisberg						
Families (Brooklyn,N.Y.)	48.23	30.53	21.24	904	0.66	0.42
Wiener-Rothberg-Fox						
Mothers	50.32	28.63	21.05	461	0.069	0.79
Children	50.71	29.98	19.31	497	1.06	0.30
Schiff						
Berlin	49.44	30.94	19.62	3333	0.0089	0.92
Wolgadeutsche	48.89	23.38	27.78	180	0.078	0.78
Shigeno						
Japanese	45.80	30.30	23.90	202	1.30	0.25
Blaurock						
Cologne	49.1	29.1	21.5	2000	0.17	0.68
Thomsen-Clausen						
Copenhagen	44.57	29.86	25.57	442	1.36	0.24
Lattes-Garrasi						
Italians	57.4	27.2	15.4	430	12.17	<0.001
Kossovitch						
French	45.80	33.00	21.20	400	2.17	0.14
Laubenheimer						
Frankfurt a. M.	52.9	27.0	20.1	1000	4.10	0.05

The formula to be used when determining the value of χ^2 is therefore the same whether absolute values or percentage frequencies are used. When determining the value of P, take the number of degrees of freedom (n) equal to one. A table of χ^2 is given in Fisher's book (16). As shown in Table 2, the agreement between observation and expectation is good except in one case (Lattes-Garrasi). This case has already been discussed (see Part I).

PART III. THE RELATION $(\overline{MN})^2 = 4\overline{M} \times \overline{N}$

From equations (1), (2), and (3), it follows that

$$(\overline{MN})^2 = 4\overline{M} \times \overline{N} \tag{30}$$

If R, S, and T are the *true* frequencies of types M, N, and MN in the population, and R', S', and T' the corresponding observed frequencies, to test the accuracy of equation (30), it is necessary to obtain the standard error of

$$T'^2 - 4R'S' = K$$

From (7), (8), and (9), it follows that

$$(T'^2 - 4R'S') - (T^2 - 4RS) = 2Tz - 4Ry - 4Sx$$

(neglecting terms containing x, y, and z to the second power)

$$\sigma_K^2 = f[(T'^2 - 4R'S') - (T^2 - 4RS)]^2$$
$$= 4[T^2 f(z^2) + 4R^2 f(y^2) + 4S^2 f(x^2) - 4RTf(yz) - 4STf(xz) + 8RSf(xy)]$$

The values of $f(x^2)$, $f(y^2)$, and $f(z^2)$ are given in equations (12), (13), and (14). And according to equation (23),

$$f(xy) = -\frac{RS}{V}$$

Since, by similar reasoning, $f(yz) = -\dfrac{ST}{V}$ (31)

and $f(xz) = -\dfrac{RT}{V}$ (32)

It follows that $V\sigma_K^2 = 4[(4RS + T^2)(1 - T) - 16R^2S^2 + 8RST^2]$

Since we can take $4RS = T^2$,

$V\sigma_K^2 = 4[(T^2 + T^2)(1 - T) - T^4 + 2T^4] = 4T^2$

$$\sigma_K = \frac{2T}{\sqrt{V}} \tag{33}$$

The same result can be derived from the estimate of χ^2 given in the previous section as follows:

Since $\chi^2 = \frac{(T^2 - 4RS)^2 V}{(2R+T)^2(2S+T)^2}$ for one degree of freedom, we can take $\frac{(T^2 - 4RS)\sqrt{V}}{(2R+T)(2S+T)}$ with unit standard error, so that we can take $T^2 - 4RS$, with a standard error $\frac{(2R+T)(2S+T)}{\sqrt{V}}$

Or, $$\sigma_K = \frac{(2R+T)(2S+T)}{\sqrt{V}}$$

But, $(2R+T)(2S+T) = 4mn = 2T$ (from equations (26) and (27))

Therefore, $$\sigma_K = \frac{2T}{\sqrt{V}}$$

We can therefore test the theory by determining whether or not $T'^2 - 4R'S'$ differs significantly from zero, when compared with its standard error, which is given by equation (33). The results obtained are essentially equivalent to those obtained by the χ^2 method.

PART IV. THE MOST EFFICIENT ESTIMATE OF THE FREQUENCIES OF THE GENES M AND N

Fisher (16) defines the most efficient approximation of a statistic as the one with the smallest standard error. According to Fisher, the value obtained by applying the method of maximum likelihood is always an efficient statistic. It will now be shown that this statement also applies to the calculation of the frequencies of genes M and N.

As shown in equation (26) and (27), the maximum likelihood approximation of the frequencies of genes m and n is as follows:

$$m_1 = \overline{M} + \frac{\overline{MN}}{2} \tag{34}$$

$$n_1 = \overline{N} + \frac{\overline{MN}}{2} \tag{35}$$

(These formulae are self-evident, since the frequency of each gene is necessarily equal to the frequency of the corresponding homozygous type plus half the frequency of the heterozygote.)

Since $m_1' = R' + \frac{T'}{2}$

and $m_1 = R + \frac{T}{2}$

$$\sigma_{m_1}^2 = f(m_1' - m_1)^2 = f\left[\left(R' + \frac{T'}{2}\right) - \left(R + \frac{T}{2}\right)\right]^2$$

From (7) and (9), it follows that

$$\sigma_{m_1}^2 = f\left(x + \frac{z}{2}\right)^2 = f(x^2) + \tfrac{1}{4}f(z^2) + f(xz)$$

Substituting the values of $f(x^2)$, $f(z^2)$, and $f(xz)$ from equations (12), (14), and (32), we have

$$\sigma_{m_1}^2 = \frac{4R + T - (2R + T)^2}{4V}$$

If we now set $\frac{2R + T}{2} = m$, or $2R + T = 2m$, we have

$$\sigma_{m_1}^2 = \frac{2m + 2R - 4m^2}{4V} = \frac{2m + 2m^2 - 4m^2}{4V} = \frac{2m(1 - m)}{4V} = \frac{mn}{2V}$$

Since the formula for σ_{m_1} is symmetrical with respect to m and n, it follows that

$$\sigma_{m_1} = \sigma_{n_1} = \sqrt{\frac{mn}{2V}} \qquad (36)^4$$

A second estimate of the frequencies of the genes M and N was given in equations (4) and (5), namely,

$$m_2 = \sqrt{\overline{M}} \qquad (37)$$

$$n_2 = \sqrt{\overline{N}} \qquad (38)$$

From equations (17) and (18), it follows that

$$\sigma_{m_2}^2 = f(m_2' - m_2)^2 = \frac{1}{4R} f(x^2) = \frac{1}{4R} \cdot \frac{R(1 - R)}{V}$$

$$\sigma_{m_2} = \tfrac{1}{2}\sqrt{\frac{1 - R}{V}}$$

Since $R = m^2$

$$\sigma_{m_2} = \tfrac{1}{2}\sqrt{\frac{1 - m^2}{V}} \qquad (39)$$

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[4] In a previous paper (*Jour. Immunol.*, 1932, 21, page 165), this formula was erroneously given as $\sigma m = \sigma n = \sqrt{\frac{mn}{V}}$

$$\sigma_{n_2} = \tfrac{1}{2}\sqrt{\frac{1-n^2}{V}} \tag{40}$$

To determine the relative efficiency of the two estimates of the frequencies of the genes M and N given above, it is necessary to ascertain whether $\sigma_{m_1}/\sigma_{m_2}$ is greater or less than one.

$$\sigma_{m_1}/\sigma_{m_2} = \sqrt{\frac{m(1-m)}{2V}} \div \sqrt{\frac{1-m^2}{4V}}$$

$$\frac{\sigma_{m_1}}{\sigma_{m_2}} = \sqrt{\frac{2m}{1+m}} \tag{41}$$

Since $m \leqq 1, \qquad 2m \leqq 1+m$

Hence, $\sigma_{m_1} \leqq \sigma_{m_2}$

Similarly, $\sigma_{n_1} \leqq \sigma_{n_2}$

Therefore, m_1 and n_1 are better estimates of the frequencies of genes M and N than m_2 and n_2.

Wellisch (19) claims that his approximations of the frequencies of genes M and N, obtained by his method of "Ausgleichung," are the best. The formulae that he suggests are derived as follows:

$$m' = \sqrt{\overline{M}} \qquad n' = 1 - m' = 1 - \sqrt{\overline{M}}$$

$$n'' = \sqrt{\overline{N}} \qquad m'' = 1 - n'' = 1 - \sqrt{\overline{N}}$$

$$m_3 = \frac{m' + m''}{2} = \frac{1 + \sqrt{\overline{M}} - \sqrt{\overline{N}}}{2} \tag{42}$$

$$n_3 = \frac{n' + n''}{2} = \frac{1 - \sqrt{\overline{M}} + \sqrt{\overline{N}}}{2} \tag{43}$$

$$\sigma_{m_3}^2 = f(m_3' - m_3)^2 = \tfrac{1}{4} f[(1 + \sqrt{R'} - \sqrt{S'}) - (1 + \sqrt{R} - \sqrt{S})]^2$$

Hence, $\sigma_{m_3}^2 = \tfrac{1}{4} f\left[\frac{x}{2\sqrt{R}} - \frac{y}{2\sqrt{S}}\right]^2$, from equations (15) and (16)

Or, $$\sigma_{m_3}^2 = \frac{1}{4}\left[\frac{1}{4R} f(x^2) - \frac{1}{2\sqrt{RS}} f(xy) + \frac{1}{4S} f(y^2)\right]$$

From equations (12), (13), and (23), it follows that

$$\sigma_{m_3}^2 = \frac{1 - R + 2\sqrt{RS} + 1 - S}{16V}$$

Since $R = m^2$, and $S = n^2$,

$$\sigma_{m_3}^2 = \frac{2 - (m-n)^2}{16V}$$

Similarly, $$\sigma_{n_3}^2 = \frac{2 - (n-m)^2}{16V}$$

Hence, $$\sigma_{m_3} = \sigma_{n_3} = \frac{1}{4}\sqrt{\frac{2 - (2m-1)^2}{V}} \qquad (44)$$

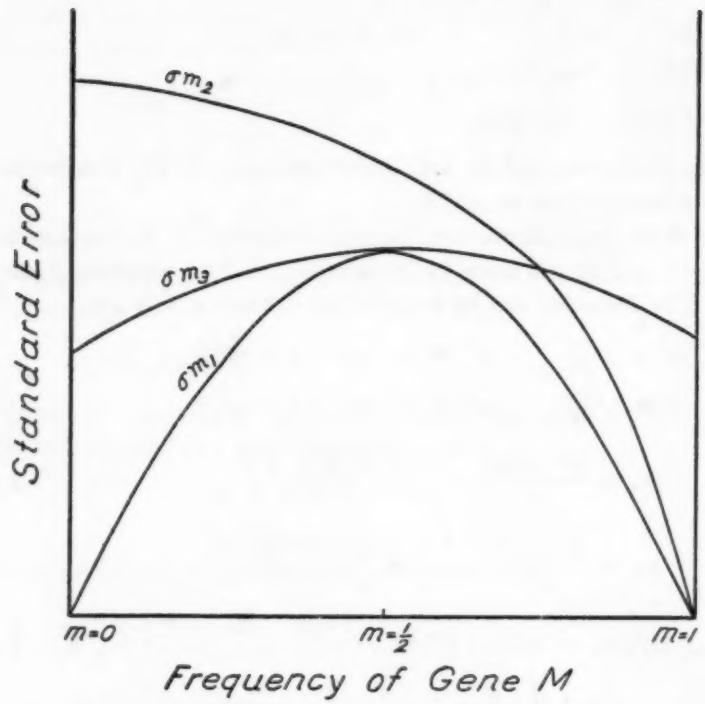

FIG. 1. COMPARISON OF THE STANDARD ERRORS OF THE VALUES m_1, m_2, AND m_3

In Fig. 1, the values of σ_{m_1}, σ_{m_2}, and σ_{m_3} are graphically represented for all values of m from 0 to 1. It may readily be seen that $\sigma_{m_3} > \sigma_{m_1}$, except when $m = \frac{1}{2}$, for which value $\sigma_{m_3} = \sigma_{m_1}$. m_3 and n_3 are therefore less efficient approximations of the frequencies of the genes M and N, than the statistics m_1 and n_1. Furthermore, $\sigma_{m_3} < \sigma_{m_2}$ only

when $m < 3/4$, and when $m > 3/4$, $\sigma_{m_3} > \sigma_{m_2}$. Therefore, since Wellisch's method of "Ausgleichung" gives a poorer estimate than m_2 for certain values of m, and furthermore, since it is less efficient than m_1 except for the value $m = \frac{1}{2}$, it has no advantage. The estimates m_1 and n_1 should always be used since they are the most efficient, and also the easiest to calculate.

The values m_1, m_2, and m_3, are all consistent statistics, since they all conform to the requirements of the theory of heredity proposed by Landsteiner and Levine; but of these three estimates, m_1 is the most efficient statistic for all values of m. As Fisher has pointed out, it is possible to invent numerous methods of calculating consistent statistics. As an example, one additional approximation of the frequencies of genes M and N will be given, namely that value which makes χ^2 a minimum.

$$\chi^2 = \frac{(a - a_0)^2}{a_0} + \frac{(b - b_0)^2}{b_0} + \frac{(c - c_0)^2}{c_0}$$

$$a_0 = Vm^2$$

$$b_0 = V \cdot 2mn = 2Vm(1 - m)$$

$$c_0 = V(1 - m)^2$$

If we now set $\frac{d\chi^2}{dm} = 0$, we obtain the following equation:

$$4m^2(c^2 - a^2) + (2m - 1)(4a^2 + b^2) = 0 \qquad (45)$$

There are two roots to this equation, but the value desired (m_4) is that root which lies between 0 and 1.

m_4 and n_4 are efficient estimates of the frequencies of genes M and N provided that the number of individuals in each class (M, N, and MN) is not too small. It would therefore be unsuitable, for example, for determining the frequencies of the genes M and N in the population of American Indians given in Table 2 (72 type MN, 123 type M, and 10 type N), because there are too few individuals of type N. This objection could be overcome by examining a large enough sample of the population, but this is not always practicable.

It may be of interest to point out one additional advantage that the estimates m_1 and n_1 have over the other estimates of the frequencies of genes M and N. m_2, m_3, and m_4 are only valid when the population that is being studied is at equilibrium. On the other hand m_1 and n_1 are always efficient estimates of the frequencies of genes M and N,

even if the population studied is not homogeneous, provided only that the sample of the population examined is truly representative.[5]

PART V. APPLICATION OF THE AGGLUTINOGENS M AND N FOR THE EXCLUSION OF PATERNITY

From the view-point of the application in cases of disputed paternity, the heredity of the agglutinogens M and N can be summarized in the following two laws:

(1) The agglutinogens M and N cannot appear in the blood of any individual unless they are present in the blood of one or both parents.

(2) A type M parent cannot give rise to a type N child, and a type N parent cannot have a type M child.

If the chances of proving non-paternity by using the first law be represented by w_1, and the chances of excluding paternity under the second law by w_2, we have [6]

$$w_1 = mn(1 - 3mn) \tag{46}$$

$$w_2 = 2\overline{M} \times \overline{N} = 2m^2n^2 \tag{47}$$

$$w_1 + w_2 = mn(1 - mn) \tag{48}$$

It is therefore possible to predict the percentage of exclusions to be expected under each law.

According to Schiff (see Table 2), the frequencies of the three types in Berlin are: type M, 30.94 per cent; type N, 19.62 per cent; and type MN, 49.44 per cent.

Therefore, $m = \overline{M} + \frac{\overline{MN}}{2} = 55.66$ per cent

and $n = 44.34$ per cent

$w_1 = 6.51$ per cent

$w_2 = 12.18$ per cent

$$P_1 = \frac{w_1}{w_1 + w_2} = 34.8 \text{ per cent}$$

$$P_2 = \frac{w_2}{w_1 + w_2} = 65.2 \text{ per cent}$$

In 1051 forensic cases, Schiff (9) obtained 94 exclusions of paternity as follows:

Child M—Putative Father N	35
Child N—Putative Father M	29

[5] Cf. *Jour. Immunol.*, 1931, 21, pp. 162-165.

[6] Cf. *Jour. Immunol.*, 1930, 19, pp. 271-275.

Child MN—Supposed Parents both M.....	22
Child MN—Supposed Parents both N	8
Total	94

Therefore, $P_1' = \frac{30}{94} = 31.9 \pm 4.8$ per cent

$P_1' - P_1 = 2.9 \pm 4.8$ per cent

Since the difference between the observed and theoretically expected frequencies is less than the standard error, this analysis of Schiff's medicolegal statistics furnishes further independent evidence of the validity of the theory of Landsteiner and Levine.

PART VI. THE APPLICATION OF AGGLUTINOGENS M AND N TO THE STUDY OF TWINS

It is to be expected that monovular or identical twins belong to the same type. On the other hand, identical types should occur no more frequently in biovular twins than in ordinary siblings. This *a priori* expectation has actually been realized in studies made by Schiff and Verschuer (17, 18) on the agglutinogens M and N in twins.

TABLE 3

Frequency of Identical Types in Non-identical Twins

PARENTS	FREQUENCY OF MATING	PER CENT CHILDREN OF TYPES			FREQUENCY OF CHILDREN OF SAME TYPE
		M	N	MN	
M × M	m^4	100	0	0	m^4
N × N	n^4	0	100	0	n^4
M × N	$2m^2n^2$	0	0	100	$2m^2n^2$
M × MN	$4m^3n$	50	0	50	$2m^3n$
N × MN	$4mn^3$	0	50	50	$2mn^3$
MN × MN	$4m^3n^3$	25	25	50	$\frac{3m^2n^2}{2}$

It is of practical importance to be able to predict the frequency of identical blood types in non-identical twins. This may be calculated as indicated in Table 3.

$$\text{Therefore,} \quad W = m^4 + n^4 + 2m^2n^2 + 2m^3n + 2mn^3 + \frac{3m^2n^2}{2}$$

$$\text{Or} \quad W = (1 - mn)^2 + \frac{m^2n^2}{2} \tag{49}$$

In New York City, for example, since $m = 46.2$ per cent, and $n = 53.8$ per cent,

$W = 59.6$ per cent.

Therefore, by means of the agglutinogens M and N, 40.4 per cent of biovular twins can be recognized.

Similarly, by using the classic Landsteiner blood groups, O, A, B, and AB, it can be shown that for a population like that present in New York City, approximately 40 per cent of biovular twins can be recognized as such. Therefore, by the combined use of the four agglutinogens, A, B, M, and N, almost two-thirds of non-identical twins can be recognized. Blood grouping is therefore a valuable additional criterion for determining whether or not twins are identical.

SUMMARY

The theory of Landsteiner and Levine concerning the heredity of the agglutinogens M and N was subjected to a number of statistical tests, and in each case was found to conform to expectation. There can therefore be no doubt concerning the validity of this theory. The practical usefulness of the agglutinogens M and N as an additional criterion for determining whether or not twins are identical was also discussed.

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VITAL FUNCTION STUDIES

XIII. THE INFLUENCE OF ABNORMAL SITTING HEIGHT INDICES ON WEIGHT AND LUNG VOLUME PREDICTIONS

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SHORTLY after the close of the World War, a series of prediction tables for weight, chest girth, and lung volume were published by Dreyer (1). In the case of the first named, correlations were established with "trunk length" (sitting height) and chest girth, in the second with the sitting height, and in the third with the two foregoing and with body weight. Separate standards were established for men and women, and in the case of the lung volume ("vital capacity") three separate prediction tables were prepared to make allowance for differences in employment and usual activity. The basic data were derived from the study of a number of normal healthy men and women "sufficient to secure a degree of accuracy that should prove entirely satisfactory."

Theoretically, from a series of simple and easily secured measurements normal values could be predicted for each individual and the deviation of the observed from the calculated magnitudes allowed to assume that diagnostic import which further study should warrant. More recently, Myers, in an admirable monograph (2) has summarized the clinical indications of changing lung volume.

The Dreyer generalizations have a definite potential value which is unfortunately only partly capable of realization. As I pointed out some years ago (3), Dreyer's measurements were made upon people of substantially normal bodily configuration. Significant departures from this criterion, as in emaciation and even more disturbingly in obesity, lead to extrapolations in the chest and weight correlations that wholly invalidate them for general use. To repeat an illustration, a patient 150 cm. tall and weighing 129.5 kilograms is 5 per cent below her predicted weight if the mean of the sitting height and chest formulas be used. Actually, by the trunk height, she was 179 per cent overweight.

* Dr. Rowe died December 6, 1934.

The sitting height, on the other hand, is free from these sources of error as it is determined by the bony structure of the upper half of the body. For this reason, it offers a sound starting point from which to derive predictions for comparative analysis. For many years past, it has been the practice of this institution to include such comparisons referred to weight and lung volume on the basis of the sitting height correlation as a routine procedure in the diagnostic survey. The weight relationships are particularly valuable in cases under observation for long periods of time and especially where growing children are involved. A further and most significant indirect implication lies in the relationship of nutritional level to basal metabolic rate. The estimation of the authority of the measurement of this latter magnitude derives in part from a correlation of the observed rate with this and similar associated evidences.

It was patent from the start, however, that while sitting height as a criterion of prediction usually could not lead to the gross errors of extrapolation inherent in the other two standards, it was yet subject to variation within its own limits and these might attain a disturbing magnitude in extreme cases.

The sitting height, in the individual of relatively normal configuration, is slightly more than half of the total standing height which, of course, roughly summates all of the weight-producing factors of the individual. They are both linear measurements and so equally incompetent to define rigorously a relationship existing in three dimensional space. Dreyer's method of approach, however, by the collation of a number of actual observations, establishes average weights for average sitting heights. This method of averages, however, implies that the weight is predicted from a sitting height which maintains the average relation to the entire body. This, of course, is not the case with many individuals and thus relatively large sitting heights, taken in relation to the total, indicate a total body weight definitely superior to that which would be normal for the properly proportioned person. As a corollary, sitting heights significantly below median values predict weights that are definitely too low.

THE SITTING HEIGHT INDEX

The relationship of the sitting to the total height, usually termed the Sitting Height Index, offers a means both of estimating the authority of the prediction and also, as will be discussed in the body of

this paper, permits the calculation of a corrective factor which brings the prediction more nearly in accord with fact. The normal—or average—sitting height index has been a matter of investigation by many, and representative values are available in the literature. Pfitzner, quoted by Bean (4), offers values ranging from 0.531 to 0.518 progressing inversely with standing height, while the latter author gives 0.525 as the mean of two thousand separate observations. My own values, derived from several thousand independent measurements, show a slight sex difference, 0.524 being the average for the male, while 0.533 more nearly represents the female proportion. Racial factors would undoubtedly influence these magnitudes somewhat, but the values as given may be felt to present fairly the data from the composite population of the New England states. The data from several consecutive series which have been studied in other connections may serve to document the position. For convenience, these are collected in tabular form.

TABLE 1

Sitting Height Indices

GROUP	NUMBER	INDEX	FEMALES (%)
Control (male)	500	0.524	0
Not Endocrine	800	.529	61
Pituitary	700	.530	61
Thyroid	350	.531	75
Gonad	350	.533	97
Control (female)	500	.533	100

The control groups were largely college students from institutions in and about Boston. The group designated as "Not Endocrine" were patients drawn from the diagnostic service of the Evans Memorial and who exhibited morbid states unassociated with the ductless glands and presenting a wide variety of conditions. The other groups derived from the same service but each of them gave evidence of disturbed endocrine function associated with the gland whose name it bears. The sex difference would seem to be established, at least for this group of over three thousand unselected individuals. While the normal individuals whose

collated data determine these averages will show a considerable plus and minus scatter from the mean, the magnitude of the individual deviations is seldom large. When, however, patients presenting metabolic disorders, particularly those influencing growth, come under consideration, quite a different state of affairs is encountered. The pituitary giant attains the characteristic altitude through overgrowth of the long bones, while the achondroplastic dwarf and one type of pituitary aberration with early epiphyseal closure define the other extreme. Indices as low as 0.48 are encountered in the first and as high as 0.66 in the second group. Obviously in these extreme cases—and in not a few of those which bridge the gap between the limiting values and the mean —weight prediction as based upon sitting height fails to make due allowance for the contribution of the lower half of the body. While predictions never reach such erroneous extremes as do those deriving from the chest and weight relationships as illustrated above, it is still possible for the arithmetical expression of the deviation from predicted weight to assume frankly misleading proportions.

Dreyer's values have formed the basis of the earlier comparisons, and in the present study it has seemed wholly desirable to utilize the large amount of carefully observed and compiled material which constitutes his prediction tables.

In utilizing the Dreyer book, it is to be noted that several of his formulae, notably the weight prediction from trunk, are incorrect and that the tabulated data do not derive from these equations but from those embodied in an earlier paper (5). I had remarked this in 1925 while making an analysis of Dreyer's data and have recently learned [1] that Dr. Louis Dublin in a similar analysis called attention to this fact in 1922.

EFFECT OF SITTING HEIGHT INDEX ON PREDICTION OF WEIGHT FROM HEIGHT

For this material to be useful it must be adapted for application over a wide range of physical variation. To ascertain if this criterion is uniform over the ranges contemplated, a series of ratios were computed for varying heights and sitting height indices and are given in Table 2.

[1] Personal communication.

TABLE 2

Ratio of Weight Deviation at Different Heights

STANDING HEIGHT	S. H. INDICES	MALE		FEMALE	
		Predicted Weight	Ratio	Predicted Weight	Ratio
120	0.470	14.91	1.831	15.18	1.852
	0.570	27.30		28.11	
140	0.470	24.18	1.830	24.83	1.852
	0.570	44.26		45.99	
160	0.470	36.74	1.831	38.05	1.852
	0.570	67.26		70.46	
180	0.470	53.15	1.831	55.40	1.853
	0.570	97.31		102.66	
200	0.470	73.96	1.830	77.66	1.852
	0.570	135.38		143.73	

From the total heights, as given in the first column, the sitting heights were calculated severally for each of two rather widely separated indices. From these in turn the predicted weights were taken from the appropriate tables in the monograph (Male, Table I, and Female, Table VII). Dividing the smaller into the larger, the weight ratios are determined and are found to be uniform for each sex throughout the selected range of heights. Further, the magnitude of the ratio indicates clearly how large an error in prediction may be present where marked disproportion exists in the usual bodily relations.

To determine limits of tolerance within which the prediction error may be ignored, a second series of calculations have been made and the results collected in Table 3.

Formula

$$\text{Deviation in per cent} = \frac{\text{Predicted Weight—Ideal Normal Weight}}{\text{Ideal Normal Weight}}$$

or

$$-29 \text{ per cent} = \frac{44.44 - 62.53}{62.53}$$

TABLE 3

Variation of Predicted Weight With Sitting Height Index

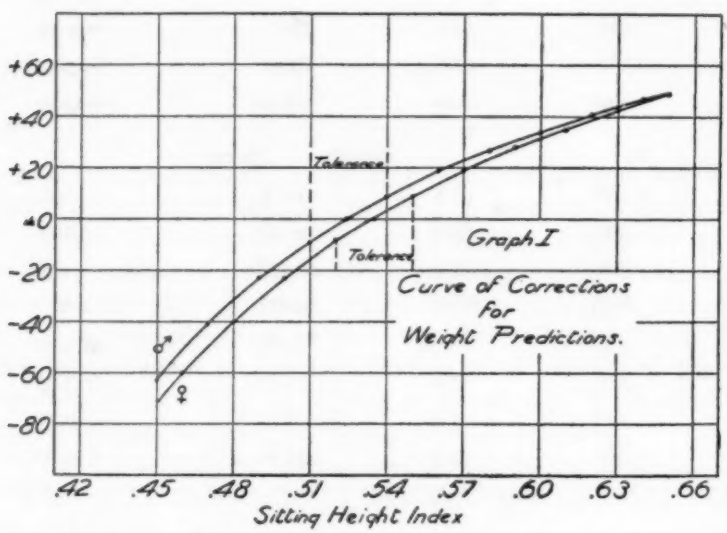
	INDEX	TRUNK (*cm.*)	PREDICTED WEIGHT (*kg.*)	DEVIATION *Kilogram*	DEVIATION %
	A.		*Male* 170 cm.		
	0.470	79.9	44.44	—18.09	—29
	.490	83.3	50.64	—11.89	—19
Tolerance	.510	86.7	57.40	— 5.13	— 8
Tolerance	**.524**	**89.1**	**62.53**	**± 0**	**± 0**
Tolerance	.540	91.8	68.66	+ 6.13	+10
	.560	95.2	76.96	+14.43	+23
	.580	98.6	85.90	+23.37	+37
	.600	102.0	95.53	+33.00	+53
	B.		*Female* 160 cm.		
	0.480	76.8	40.69	—16.22	—29
	.500	80.0	46.36	—10.55	—19
Tolerance	.520	83.2	52.55	— 4.36	— 8
Tolerance	**.533**	**85.3**	**56.91**	**± 0**	**± 0**
Tolerance	.550	88.0	62.86	+ 5.95	+10
	.570	91.2	70.46	+13.55	+24
	.590	94.4	78.67	+21.76	+38
	.610	97.6	87.51	+30.60	+54

Assuming a typical male of 170 cm. in height and a female of 160 cm., the trunk heights for a range of indices have been calculated and the corresponding weight predictions ascertained from the tables. Assuming that the weight corresponding with the respective average normal indices is that of the "normal," the deviations of the predictions for the several indices have been computed. In the case of the male, the error is 10 per cent or less within the range of 0.510 to 0.540, while the like limits of tolerance for the female fall between 0.520 and 0.550, the sex difference reflecting that of the basic datum.

By the ordinary method of comparison, however, the arithmetical procedure is somewhat different. Ordinarily, the predicted weight corresponding to the observed sitting height is taken from the table and this is then divided into the observed weight to ascertain the deviation of the latter from the normal. To illustrate, a male with an observed sitting height of 90 cm. has a predicted weight of 64.53 kilograms. If his actual weight as observed was 70.0 kilograms, he is 108 per cent of his prediction or 8 per cent overweight.

CORRECTIONS FOR SITTING HEIGHT INDEX

Adopting the same convention of equating the normal index with its weight prediction as the normal, the errors involved from varying



GRAPH 1. CURVES OF CORRECTION FOR INDICATED WEIGHT DEVIATION WITH VARYING SITTING HEIGHTS

indices within possible limits have been computed. Data from the average male of 170 cm. and female of 160 cm. have been chosen. These constitute corrective factors and for practical use can most conveniently be recorded graphically (Graph 1).

Formula for Correction Curve.

$$\text{Correction in per cent} = \frac{\text{Predicted Weight} - \text{Ideal Normal Weight}}{\text{Predicted Weight}}$$

or

$$-41 \text{ per cent} = \frac{44.44 - 62.53}{44.44}$$

To apply the correction, one calculates the deviation of the observed weight from that indicated in the table as normal for the observed sitting height. The correction for the observed index is then read from the graph and applied directly to the initial value. To illustrate, in the foregoing example the first comparison showed an individual with a +8 per cent weight deviation. Assuming that the index was 0.56, for which the correction factor is +19 per cent, then actually the subject was 27 per cent overweight.

TABLE 4

Data From Patients With Abnormal Sitting Height Indices

NO.	SEX	AGE	HEIGHT	TRUNK	INDEX	WEIGHT	DIAGNOSIS
1	M	19	131.8	63.6	0.483	35.4	Congenital Lues
2	M	26	228.6	110.5	.483	163.3	Acromegalic Giant
3	F	35	166.9	81.0	.485	65.3	Acromegaly
4	F	36	188.0	93.8	.498	71.6	Hypothyroid (earlier Pituitary)
5	M	45	170.0	85.2	.501	70.9	Pituitary Dysfunction
6	F	34	113.6	58.0	.511	21.8	Pituitary Dwarf
7	M	8	121.5	67.3	.554	25.4	Hypothyroid
8	M	36	105.3	58.5	.556	22.7	Pituitary Dwarf
9	F	18	149.4	83.8	.561	54.5	Pituitary Failure
10	F	4.5	120.6	68.9	.572	23.2	Pituitary Pubertas Praecox
11	M	4.5	129.4	74.4	.577	28.8	Pituitary Pubertas Praecox
12	F	13	131.5	78.5	.597	41.4	Achondroplasia

To test the applicability of this approach, a small group of twelve cases has been selected, each of whom presents a departure from the sitting height index of very tangible proportions. The basic data for the group have been collected in Table 4.

Half of the group show low, the remainder high indices. The age range is from 4.5 years to 45, the heights from the pituitary dwarf (No. 6) to the acromegalic giant (No. 2). There is a wide scatter in weights but the extremely obese have been omitted and will be considered separately. The weight deviations for this group have been reached by three methods: A, the predicted weight has been taken directly from the table; B, the ideal sitting height has been calculated from the standing height and the normal index and then the corresponding weight prediction taken from the table; and C, the correction from the curve has been applied to the direct deviation (A). The results are grouped in Table 5.

TABLE 5

Weight Deviations

NO.	A. DIRECT		B. CORRECTED		C. FROM CURVE	DIFF.
	Kilogram	%	*Kilogram*	%	%	B-C
1	+13.7	+63	+ 7.3	+26	+34	— 8
2	+40.5	+33	+ 3.8	+ 2	+ 4	— 2
3	+17.1	+35	+ 0.1	± 0	— 1	+ 1
4	— 5.5	— 7	—23.6	—25	—30	+ 5
5	+16.6	+30	+ 8.4	+15	+15	± 0
6	+ 5.2	+31	+ 2.7	+14	+17	— 3
7	— 0.6	— 2	+ 3.6	+17	+16	+ 1
8	+ 6.1	+36	+ 8.7	+62	+53	+ 9
9	+ 0.7	+ 1	+ 8.9	+20	+16	+ 4
10	— 5.6	—19	+ 0.1	± 0	+ 1	— 1
11	— 6.7	—19	+ 2.2	+ 8	+ 7	+ 1
12	— 2.2	— 5	+11.0	+36	+26	+10

At first sight one might assume that the indications of comparisons B and C should be identical; examination of the methods of computation will at once disclose the error of such an assumption. The curve (C) theoretically is derived from individuals whose actual weight is

normal and the deviations assume the magnitude of the prediction error as conditioned by a departure from the median value of the sitting height used.

The values in column B, on the other hand, are based upon the actual weights of people who departed significantly from normal weight as well as from normal stature. The arithmetical form of the equation determines even wider departures from the fixed curve where gross obesity—and much less significantly, severe emaciation—characterizes the individual. The differences B — C in the table serve only to illustrate that the use of the curve is permissible within a very wide range of sitting height indices and of not inconsiderable departures from actual normal weights.

The indications may be briefly reviewed and compared with the pictures of the several individuals. Case No. 1 was actually but slightly overweight, if at all; the acromegalic giant (No. 2) was certainly not obese; on the other hand, the other case of acromegaly (No. 3) which by direct prediction was apparently 35 per cent overweight was actually somewhat obese. Barring a residual characteristic girdle accumulation of adipose, case No. 4 was rather thin. Case No. 5 had a heavy body with thin legs. The pituitary dwarf (No. 6) was but slightly overweight.

In the other group, No. 8, also a pituitary dwarf, was definitely fat, and the next patient (No. 9), a girl of eighteen, was distinctly well nourished, as shown in the picture. The two children with precocious puberty were not seriously below a normal nutritional level, and the achondroplasic (No. 12) was definitely plump. In the case of the children, as noted above, correct estimations of the level of nutrition are of very real importance in evaluating the progress of the condition.

EFFECT OF OBESITY ON PREDICTION

As was previously mentioned, the very obese have been purposely omitted from this survey as the possible correlations are influenced by yet another subversive factor. As noted above, the arithmetical derivation of the correction curve imposes a definite limit to corrections deriving from high indices; the direct prediction is too high and hence it produces a minus error in the comparison which transforms naturally to a plus correction. As all minus errors have the definite limit of — 100 per cent, a limit which they cannot even nearly approach, there is a definite limitation of the applicability of the curve to those who are actually 100 per cent or more overweight. Further, with an up-

ward progress of the indices, the curve tends to become asymptotic for the reason just noted, and the correction factor becomes progressively more inadequate to compass the necessary adjustment. To render point to this criticism, four cases have been selected which exemplify the limits of application of the generalization. These data are given in Table 6.

TABLE 6

Obesity Error

DATUM	CASE			
	A	*B*	*C*	*D*
Sex	F	M	M	F
Age	24	14	16	24
Height	160.3	147.2	110.0	128.2
Trunk	90.2	88.8	72.0	84.2
Index	0.563	0.604	0.648	0.657
Weight	182.1	189.5	24.9	63.6
Deviation, direct	+168%	+207%	−22%	+ 16%
corrected	+219%	+377%	+51%	+127%
from curve	+184%	+243%	+27%	+ 70%
Difference	+ 35	+134	+24	+ 57

Diagnoses

A. Pituitary Failure
B. Pituitary Failure
C. Achondroplasia
D. Achondroplasia (Neural Pathology)

Case A is a professional "fat lady" with a demonstrated pituitary background. Her massive overweight leads to relative magnitudes with which the correction curve is incompetent to deal. This is shown even more strikingly in the next case (B) also a pituitary obesity in a boy less than five feet tall. His high sitting height index is misleading as his great weight had produced a marked bowing of the legs, lowering his standing height and raising the index unwarrantably. Truly representative measurements would lower his corrected deviation and thus the difference but would still leave a complete lack of concordance. Turning to the two achondroplasics, in the case of the boy there is an

actual change of sign between the direct and corrected values. With the girl, her obesity is so patent that the higher figure is certainly the more representative. In her case, both the high index and her great obesity militate against concordant results.

To summarize briefly, correction should be made for the weight predictions based on sitting height when they assume misleading magnitudes through abnormal sitting height indices. The simple curves which are included in this article offer an easy means of rectifying data if applied directly to the Dreyer formulations for individuals not exhibiting extreme conditions of obesity. Severe emaciation, on the other hand, while an added factor of error, never can produce seriously false values as the condition is self-limited, a state not operative in obesity.

Limiting conditions are obesity and indices superior to 0.60 or 0.61, though in the latter case the application of the correction yields a truer picture than does the direct comparison alone. Case C is an excellent illustration of this point.

PREDICTION OF LUNG VOLUME

The Dreyer chest prediction is without meaning except as applied to individuals of normal configuration. The indications are too circumscribed to warrant its use as a routine procedure.

The same is not true, however, of the prediction of lung volume ("Vital Capacity") if certain limiting conditions be recognized and due allowance made for them. These may be briefly considered seriatim.

The predictions based upon weight and chest girth are only applicable to individuals within a rather narrow nutritional zone and for that reason do not come into general consideration.

Dreyer has established three standards ("A," "B" and "C") for each sex as determined by the occupation and level of physical activity of the subject. An experience of over a decade with these figures has shown that the most exacting male standard ("A") is the one most applicable to the American man as seen in a general diagnostic clinic. On the other hand, the "B" female standard seems most nearly to correspond with the performance of the normal healthy American woman. Why this should be so is hard to explain. The average American girl of today plays games as consistently and with as much vigor as her British sister. The use of Dreyer's Female "A" standard would show the average athletic American college girl to be uniformly somewhat below prediction.

In a group of sixteen young women, all carefully studied and shown to be wholly normal in all respects and all of whom were trained and practicing athletes, the average lung capacity was 5 per cent above prediction by the "B" and 4 per cent below by the "A" standard. The "B" comparison is far more indicative of their actual level than is the "A" relationship.

In dealing with children, the female "B" standard applies to the female child with reasonable parity; with the boy up to the age of thirteen or fourteen years, the same standard is far better adapted than the male "A" to which he attains in the years of maturity. Our data on this point are not wholly conclusive but experience indicates that the above convention accords best with the other available data germane to the question.

TABLE 7

Deviation Ratio at Different Heights

STANDING HEIGHT	MALE 0.470—.480		FEMALE 0.480—.580	
	Predicted Lung Volume	Ratio	Predicted Lung Volume	Ratio
120 cm.	1466 cc. 2266 cc.	1.546	1237 cc. 1912 cc.	1.546
140 cm.	2076 cc 3208 cc.	1.545	1764 cc. 2726 cc.	1.545
160 cm.	2806 cc. 4337 cc.	1.545	2398 cc. 3706 cc.	1.545
180 cm.	3660 cc. 5657 cc.	1.545	3144 cc. 4859 cc.	1.545
200 cm.	4643 cc. 7176 cc.	1.545	....	....

Following the same procedure as with the weight predictions, Table 7 contains the necessary data for the establishment of the ratios between the high and low predictions.

It will be noted that the ratio is lower than with the weight relationships. This might well be anticipated as in the present consideration, while the change is three dimensional, it takes place within a definitely limited portion of the body which is but a fraction of the whole. It is interesting further to note that there is not the sex difference in the ratio reported in the weight measurements; this latter presumably reflects the influence of secondary sex characteristics.

With the lung volume, it is also desirable to establish the limits of tolerance within which direct comparisons may be made without introducing significant error. The data are found in Table 8.

TABLE 8

Variation of Predicted Lung Volume With Sitting Height Index

S. H. INDEX	A. MALE 160 CM.			B. FEMALE 150 CM.		
	Predicted Lung Volume	Deviation		Predicted Lung Volume	Deviation	
		cc.	%		cc.	%
0.47	2806	—776	—22	....	.....	....
.48	2943	—640	—18	2067	—567	—22
.49	3083	—500	—14	2168	—466	—18
.50	3226	—357	—10	2270	—364	—14
.51	3374	—209	— 6	2376	—258	—10
.52	3525	— 58	— 2	2485	—149	— 6
.524	**3583**	**± 0**	**± 0**	....	.....	....
.53	3680	+ 97	+ 3	2596	— 38	— 1
.533	....	.....	....	**2634**	**± 0**	**± 0**
.54	3838	+255	+ 7	2710	+ 76	+ 3
.55	4001	+418	+12	2827	+193	+ 7
.56	4167	+584	+16	2947	+313	+12
.57	4337	+754	+21	3069	+435	+17
.58	....	.....	....	3194	+560	+21

With the smaller deviation, the limits of tolerance are naturally somewhat more liberal. To maintain a parity with those selected for the weight comparison, one can define from 0.50 to 0.545 for the male

and 0.51 to 0.555 for the female. Further, as the measurement of lung volume involves some degree of coöperation on the part of the subject and lacks the rigorous exactitude of a weighing, even more latitude can be extended particularly to observations which fall short of prediction. In other words, the great majority of patients met within the usual scope of clinic contact will fall within the somewhat elastic limits of tolerance indicated above and not require a correction factor to delimit their indications more exactly. A few sample records from the group of patients already discussed in connection with the weight predictions will serve to illustrate this point (Table 9).

TABLE 9

Lung Volume Deviations

A. From Direct Prediction, B. From Corrected Index

NO.	LUNG VOL. OBSERVED	STANDARD	A. DIRECT		B. CORRECTED		DIFF. B-A
			cc.	%	cc.	%	
1	2070	M. A.	+ 147	+ 8	— 250	—11	—19
3	1050	F. B.	—1660	—61	—2316	—69	— 8
4	2760	F. B.	—1038	—22	—1661	—37	—15
5	4150	M. A.	+ 431	+12	+ 35	+ 1	—11
7	1410	(F. B.)	— 360	—20	— 150	—10	+10
9	2740	F. B.	— 190	— 6	+ 137	+ 5	+11
10	1700	F. B.	— 168	— 9	+ 106	+ 6	+15
11	1240	(F. B.)	— 989	—44	— 560	—31	+13
12	2220	F. B.	— 301	—12	+ 276	+14	+26
B	2290	(F. B.)	—1058	—32	— 130	— 5	+27
C	1950	M. A.	— 594	—23	+ 377	+24	+47
D	2530	F. B.	— 433	—15	+ 699	+38	+53

Four of the group, Nos. 2, 6, 8 and "A" were incompletely studied and lung volumes were not included in the brief programmes that could be conducted. The data from the remainder show a somewhat wide range of inequalities but in at least half of the series, the differences are of an order that is not significant. The performance of case No. 1, at one extreme of the scale, is certainly more accurately represented by the corrected value. The change of sign in cases 9 and 10 is not mean-

ingful as all of the values are within the normal range. This is somewhat less true for case No. 12, but her corrected value is rather higher than one would infer from her physical habitus and general health level. With the achondroplastics, the differences are truly significant but these represent the outside extremes of the entire series. Here the corrected values are probably no more if as representative of actual performance than are those derived from direct comparison.

With the accumulation of data along these lines, the time may come when the sitting height index must be considered in all lung capacity predictions. The errors intrinsic in the measurement and the lack of clear-cut normal standards render such procedure today an unnecessary refinement.

SUMMARY

There is but little to add as the several items have been discussed in the body of the paper. It may be enough to say that for weight predictions from sitting height, using the Dreyer standards, correction should be made for abnormal indices with due consideration for the limitations already noted.

A like condition does not apply to the lung volume predictions at present, although at some future time improvement in technique and in standards may render some correction desirable.

The author expresses his appreciative thanks to all those who have participated in the work. He is especially grateful for the permission to reproduce the pictures which aid so materially in the documentation of the thesis.

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Case 1. Marked Skeletal Dysplasia with Probable Congenital Luetic Background

CASE 2. ACROMEGALIC GIANT
CASE 8. PITUITARY DWARF

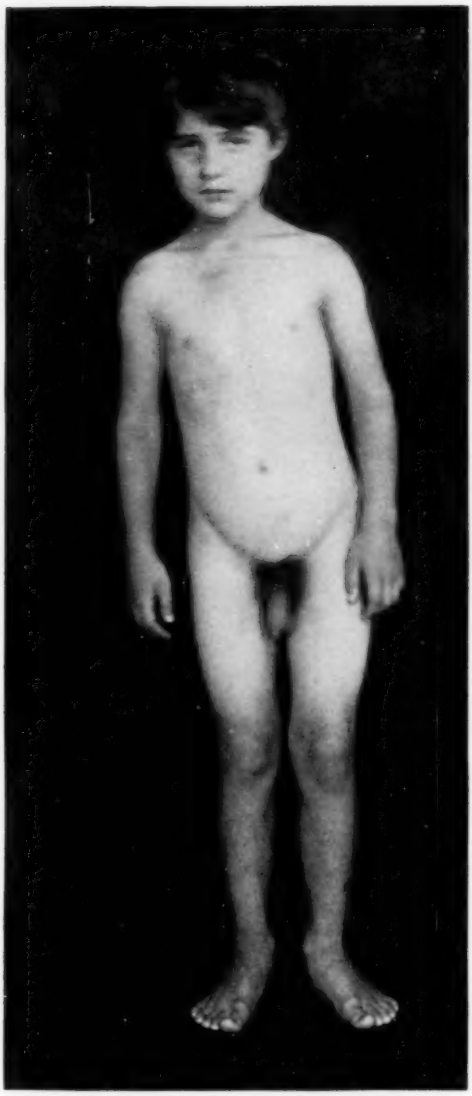
Case 3. Acromegaly. Onset in Adult Years

CASE 4. THYROID FAILURE. HYPERPITUITARISM IN EARLIER YEARS

Case 5. Pituitary Dysfunction

Case 6. Pituitary Dwarf

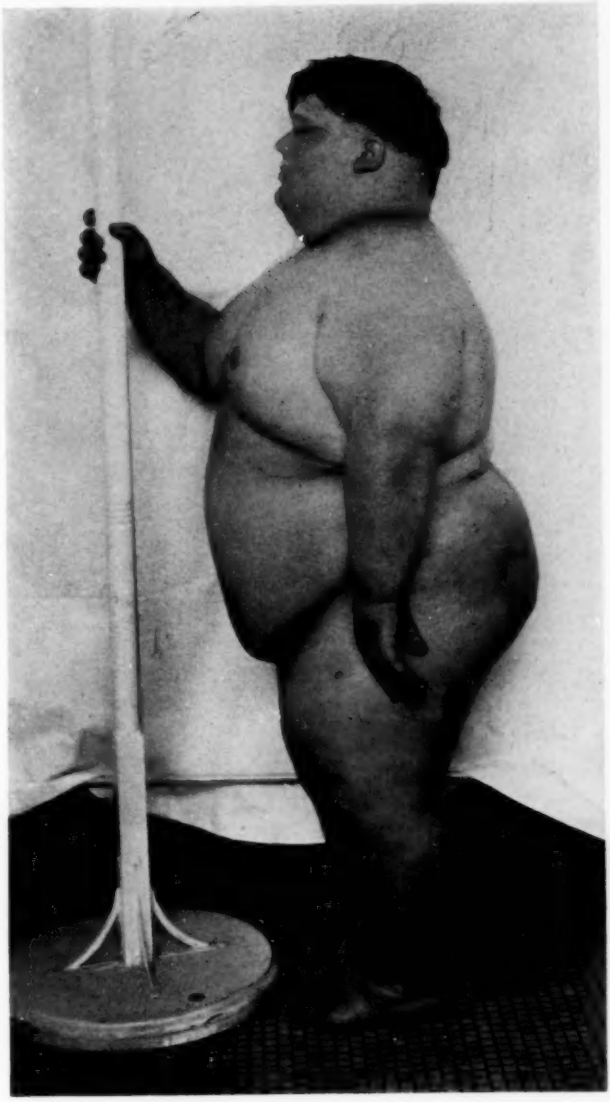
CASE 10. PUBERTAS PRAECOX (PITUITARY)



CASE II. PUBERTAS PRAECOX AND PSEUDOHERMAPHRODITISM (PITUITARY)

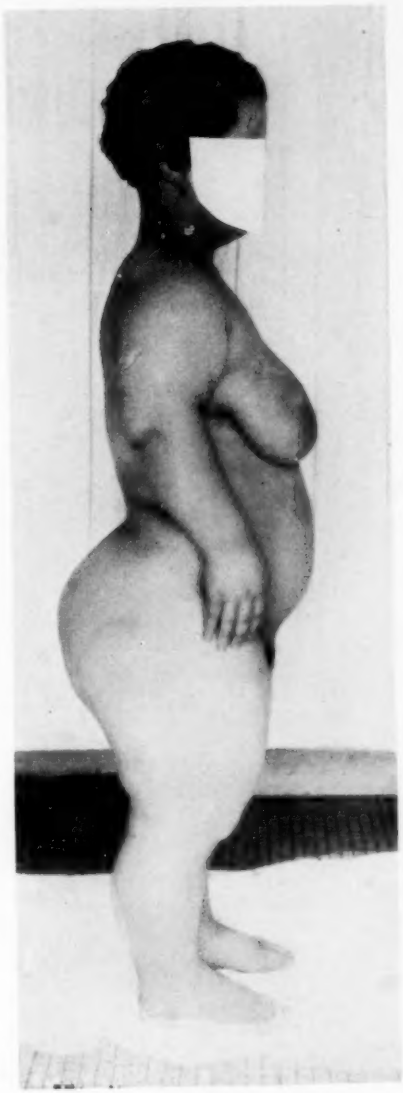
CASE 12. ACHONDROPLASIA

CASE A. PITUITARY OBESITY



Case B. Pituitary Obesity

Case C. Achondroplasic Dwarf



Case D. Achondroplasic Dwarf with Probable Neural Pathology

THE USE OF THE LOGISTIC CURVE TO REPRESENT THE PREVALENCE OF DEFECTIVE VISION AMONG PERSONS OF SPECIFIC AGES ABOVE 30 YEARS[1]

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THE logistic or growth curve described by Pearl and Reed (8, 10, 12) has been widely used by them and by others to represent population growth in various countries (9) as well as other growth functions. In a previous report (3) one of us used the logistic and the catalytic curves to describe the growth with age in the proportion of children who had at some time in their lives suffered attacks of certain communicable diseases.

In a recent study of the frequency of eye examinations in an observed population (4), it was noted that the curve of the prevalence of defective vision among males and females of specific ages above 30 years was of the logistic form. It was found that a symmetrical growth curve would fit very closely the observed values. Table 1 shows the percentages of persons who were found by eye tests to have defective vision of any degree in either eye, along with calculated values on a logistic curve fitted to the actual points. The data are the results of Snellen and Jaeger eye tests made as a part of a general physical examination of 100,924 white male and of 11,694 white female ordinary-life insurance policyholders by the Life Extension Institute and reported upon by Sydenstricker and Britten (14). The examinations were a service extended to the policyholders by the companies and did not include entrance tests made preliminary to the granting of insurance. Fig. 1 shows the actual points and the fitted curves[2] for both males and females.

---

[1] From the Office of Statistical Investigations, U. S. Public Health Service. Published by permission of the Surgeon General.

[2] The curves were fitted by the short graphic method described by Pearl and Reed (10).

TABLE 1

Prevalence of Defective Vision (Any Degree, Either Eye) Among White Males and Females of Specific Ages Above 30 Years—Based on Eye Tests Made as a Part of a General Physical Examination of 100,924 Male and 11,694 Female Ordinary-Life Insurance Policyholders by the Life Extension Institute.† The Calculated Values are Points on a Logistic Curve Fitted to the Observed Values.*

AGE IN YEARS		MALES				FEMALES			
Group	Midpoint or mean of group	Percentage with defective vision		Number with defective vision	Total number tested	Percentage with defective vision		Number with defective vision	Total number tested
		Calculated	Observed			Calculated	Observed		
30 to 34	32.5	42.26	42.04	8,073	19,204	48.41	48.87	1,147	2,347
35 to 39	37.5	43.41	43.78	8,334	19,037	50.80	50.80	1,116	2,197
40 to 44	42.5	48.87	48.60	7,156	14,723	60.82	60.74	1,049	1,727
45 to 49	47.5	63.77	64.57	6,788	10,512	72.90	72.88	895	1,228
50 to 54	52.5	77.44	77.24	5,358	6,937	76.54	75.71	561	741
55 to 59	57.5	81.89	81.73	3,297	4,034	77.11	77.90	282	362
60 to 64	62.5	82.80	82.89	1,827	2,204				
65 to 69	67.5	82.96	83.56	864	1,034	77.20‡	77.73	171	220
70 and over	75.0	83.00	82.67	434	525				

* Inability to read the Snellen or the Jaeger "normal" test letters with either eye was considered defective vision.
† Data from Sydenstricker and Britten (14).
‡ 65.0 years.

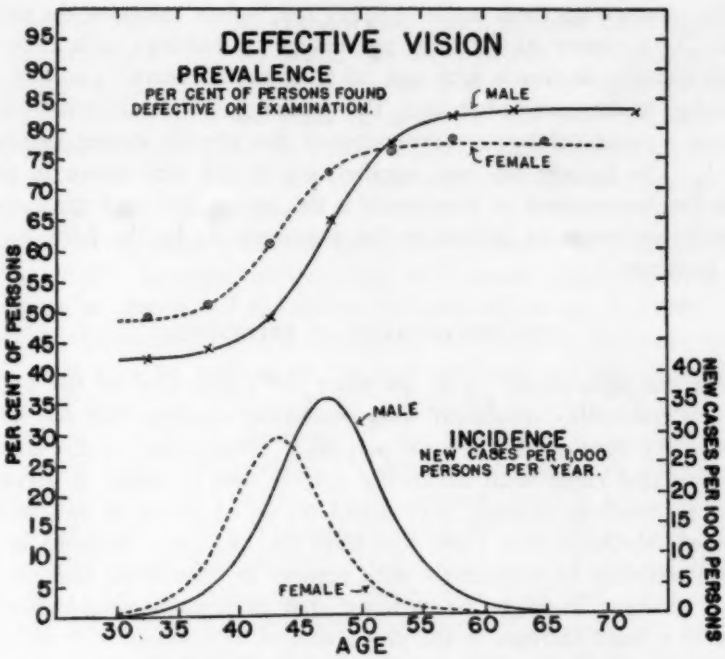

FIG. 1. PREVALENCE OF DEFECTIVE VISION (ANY DEGREE, EITHER EYE) AND THE ESTIMATED ANNUAL INCIDENCE (NEW CASES) AMONG WHITE MALES AND FEMALES OF SPECIFIC AGES ABOVE 30 YEARS

Based on Snellen and Jaeger eye tests made as a part of a general physical examination of 100,924 male and 11,694 female ordinary-life insurance policyholders by the Life Extension Institute (14). The smooth curves of prevalence are logistics and the incidence curves are differences between the computed prevalence at successive ages.

Equations for the prevalence curves follow:

$$y = \frac{K}{1 + Ce^{-rt}} + d$$

y = Percentage of persons with defective vision
d = Lower asymptote
K = Difference between upper and lower asymptote
t = Age in years

Males

$$y = \frac{41.0}{1 + 314.6e^{-.34560(t-30.5)}} + 42.0$$

Females

$$y = \frac{29.2}{1 + 155.1e^{-.40000(t-30.5)}} + 48.0$$

No attempt has been made to apply the logistic curve to the earlier ages. As a matter of fact, the percentage of children with defective vision actually decreases with age up to about 20 years[3] (1, 2, 5, 6). Likewise, in the early adult ages, the percentages with defective vision are not represented by any extension of the growth curves shown in Fig. 1. The logistic has been applied only to the ages above 30 years when the development of presbyopia is the reason for the large increase in defective vision as defined in the examinations by the Life Extension Institute.

THE DEVELOPMENT OF PRESBYOPIA

For the ages above 30 or 40 years the philosophy of the logistic curve is reasonably consistent with anatomical changes that are taking place in the eyes of middle-aged persons.[4] Presbyopia, or the changes in vision that come with advancing age, is said to begin at about 40 years, to continue actively until about 60 or 65 years of age, and to progress relatively little after that time (7, 11, 15). Because of the great variability in individuals with respect to anatomical and physiological changes, it might be expected that presbyopia would manifest itself by a small increase in the proportion of individuals with defective

[3] The decrease is all in the slight defects; the proportion of children with more marked refractive errors increases with age even under 20 years.

[4] Although the data plotted in Fig. 1 are based on observations made on different persons for each age group, they may be assumed to show approximately the same curve as would be obtained by observations on the same individuals over a period of years, unless selective factors enter in to make some age groups less representative than others with respect to the prevalence of defective vision. For example, if the insured population of the older ages is composed of a disproportionately large number of persons with normal vision (to a greater extent for their age than is true of younger policyholders for their age), then the observed defective vision rates at the older ages would be too small because of this selection of persons with better vision. If such selective factors are present in the insured population and in those of this population who presented themselves for examination they would make this defective vision curve differ from one based on periodic examinations of the same individuals.

It should be noted that the shape of the curve is quite similar for males and females so the selective factors that may have distorted the age curves would have to be assumed as having about equal force in both sexes. Since those examined were all insured persons and the service was free to them, the probability that selective factors seriously distorted the age curves is less than in examinations of less homogeneous groups.

vision in the ages under 40 years, a more rapid increase from 40 to 60, and little increase after 60 years. In other words, the curve of the prevalence of defective vision would be expected to reach an upper asymptote shortly after 60 years of age. At the other extreme, the curve might be expected to start from a lower asymptote shortly before 40 years, which would represent the prevalence of defective vision just before the onset of presbyopia.

When the eyes once become defective by reason of presbyopia, it may reasonably be expected that they will remain defective, although the degree or severity of the defect changes. One can, therefore, approximate the *incidence* or the number of *new cases* of defective vision at different ages by computing the first derivative of the integral or cumulative curve that represents the prevalence of visual defect. The first derivative indicates the slope of the cumulative curve at a given point and tells how fast persons are entering the defective vision class at that particular instant of age. In the present case it is probably more informative to consider differences between certain specific ages which would represent the *average* slope of the cumulative curve during the given age interval. This figure which tells how fast persons are becoming defective in the age interval covered would therefore indicate the incidence or the number of new cases of defective vision during this age period. The process will be clarified by a specific example: If 57 per cent of the males 45 years of age and 60 per cent of those 46 years of age have defective vision, it seems reasonable to assume that 3 per cent became defective during the 12-month interval between the ages of 45 and 46 years, that is, between 45.5 and 46.5 years.

In the two lower curves in Fig. 1 these differences have been plotted for males and females in terms of rates per thousand rather than in percentages. They represent an approximation of the number of new cases of defective vision that have their onset during each year of age.

AGE OF MAXIMUM INCIDENCE

Among females the maximum in the new cases of defective vision is reached at 43 years, whereas among males it is reached at 47 years. There are occupational and other differences between the usual environments of the two sexes that influence the use of the eyes; the earlier onset of presbyopia among females may be an expression of these environmental differences. On the other hand there are various phenomena that mark physiological age and these indicate that the female

TABLE 2

*Calculated Prevalence (Cases Existing at a Given Time) and Calculated Annual Incidence (New Cases) of Defective Vision (Any Degree Either Eye *) Among White Males and Females of Specific Ages Above 30 Years*

AGE LAST BIRTHDAY (*years*)	PREVALENCE (PER CENT) †		ANNUAL INCIDENCE (PER 1,000) ‡	
	Calculated percentage of persons at this age with defective vision		Calculated new cases of defective vision per 1,000 persons during the year between this and the preceding age	
	Males	Females	Males	Females
30	42.130	48.187	.38	.61
31	42.183	48.278	.53	.91
32	42.259	48.41	.76	1.3
33	42.36	48.61	1.0	2.0
34	42.51	48.90	1.5	2.9
35	42.72	49.33	2.1	4.3
36	43.01	49.94	2.9	6.1
37	43.41	50.80	4.0	8.6
38	43.97	51.99	5.6	11.9
39	44.73	53.58	7.6	15.9
40	45.75	55.60	10.2	20.2
41	47.11	58.06	13.6	24.6
42	48.87	60.82	17.6	27.6
43	51.07	63.74	22.0	29.2
44	53.74	66.56	26.7	28.2
45	56.83	69.09	30.9	25.3
46	60.24	71.22	34.1	21.3
47	63.77	72.90	35.3	16.8
48	67.23	74.17	34.6	12.7
49	70.42	75.10	31.9	9.3
50	73.22	75.76	28.0	6.6
51	75.56	76.22	23.4	4.6
52	77.44	76.54	18.8	3.2
53	78.90	76.75	14.6	2.1
54	80.01	76.90	11.1	1.5
55	80.84	76.996	8.3	.96
56	81.45	77.063	6.1	.67
57	81.89	77.108	4.4	.45
58	82.21	77.138	3.2	.30
59	82.43	77.159	2.2	.21
60	82.60	77.172	1.7	.13
61	82.715	77.181	1.2	.09
62	82.798	77.188	.83	.07
63	82.856	77.192	.58	.04
64	82.898	77.194	.42	.02
65	82.927	77.196	.29	.02

* Inability to read the Snellen or the Jaeger "normal" test letters with either eye was considered defective vision.

† Prevalence as represented by a logistic curve fitted to data (Sydenstricker and Britten (14)) on defective vision among ordinary-life insurance policyholders examined by the Life Extension Institute.

‡ Incidence as represented by the difference between the prevalence at a given age and the preceding age.

is anatomically and physiologically more advanced than the male of the same chronological age. One outstanding example is the age of puberty, which is one or two years earlier in the female than in the male. In spite of this earlier development and possibly earlier aging of the female, it will be remembered that the life expectancy of females of a given age is one to three years greater than that of males of the same age.[8]

It might be worth while to compare for males and females certain other points on these curves which have a meaning with respect to the development of presbyopia. Because of the inaccuracy of the kind of data used in this study, it is impossible to determine the age of the beginning of the rise in the prevalence curves that would mark the earliest ages affected by presbyopia. However, by considering the total rise from the lower to the upper asymptote one can compute for each sex the age at which the curve has risen ¼, ½, ¾, or other fraction of the total rise from the lower to the upper asymptote. By computing from the equations for the curves, these points can be defined in greater detail than is possible by reading them off the graph. The results of these computations are given in Table 3.

[8] Recent studies by Steinhaus (13) suggest that the degree of presbyopia (as compared to the average, in diopters, for the same age) is correlated with life expectancy, high presbyopia indicating a shorter average length of life. The earlier age of onset of presbyopia in females might be expected to go along with a higher average presbyopia (in diopters) among females than among males of corresponding ages, but Steinhaus found no difference between the sexes. Since the data of Steinhaus include only persons who sought eye care at a clinic (almost always for refractive errors), they would not be strictly comparable with the Life Extension data which include those with normal as well as those with defective vision.

Steinhaus attributes the greater life expectancy of females to causes such as their mode of life, rather than to any less aging as indicated by the degree of presbyopia.

If life expectancy is associated with presbyopia, then as age increases there would be a tendency toward a selection of persons with better vision in the living population. In other words, persons with defective vision would contribute more largely to the deaths than those with normal vision. If such a tendency is of importance numerically, the cumulative curves would tend to be flattened at the top or even to decline in the older ages by reason of fewer people with defective vision remaining in the living population. However, these curves have practically reached their upper asymptotes by 55 years and the effect of a possible selective mortality on their rise during the period when they are going up most rapidly would seem to be small, inasmuch as it comes at an age when mortality is not exceptionally high.

TABLE 3

	MALES (AGE)	FEMALES (AGE)	DIFFERENCE BETWEEN MALES AND FEMALES (*years*)
Age when ¼ of the total increase after 30 years in the percentage with defective vision has taken place	43.96	40.36	3.60
Age when ½ of the total increase after 30 years in the percentage with defective vision has taken place	47.14	43.11	4.03
Age when ¾ of the total increase after 30 years in the percentage with defective vision has taken place	50.32	45.85	4.47
Years between age when ¼ and ¾ of the total increase after 30 years in the percentage with defective vision has taken place	6.36	5.49	0.87

Since these are symmetrical curves, the age when ½ of the total increase after 30 years in the percentage with defective vision has taken place (median) is the same as the age of maximum annual increase in the prevalence of defective vision (mode) as represented by the curves of the incidence of new cases in the lower part of the figure. This modal age in the incidence also represents the point of inflection in the cumulative prevalence curve.

As already noted, the age of maximum incidence of new cases of defective vision or the age when ½ of the total increase after 30 years in the percentage with defective vision has taken place comes 4 years earlier in females than in males. Considering the age when ¼ of the total increase after 30 years has taken place, the difference between the sexes is 3.6 years as compared to a difference of 4.5 years in the age when ¾ of this increase has taken place. This increase in the difference between the ages of males and females for these respective points indicates that not only does the female curve of the prevalence of defective vision start increasing at an earlier age, but the rise is completed in a shorter time than in the case of males. The same phenomenon appears in the last line of Table 3, which shows that the

middle half of the increase in the percentage with defective vision takes place in 5.5 years for females as compared to 6.4 for males.[6] The difference between the lower and upper asymptotes, which measures the total increase after 30 years in the percentage with defective vision, is less among females than males. However, of the total increase that occurs, the middle half takes place in nearly a year less time among females than males.

To summarize, the Pearl-Reed logistic curve was fitted to data on the percentage of males and females with defective vision (any degree, either eye) at specific ages from 30 years to the end of life. This curve apparently gives a good description of the growth of presbyopia in the population during these ages. From the curve there is computed the number of new cases of defective vision per 1,000 persons at each year of age.

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[6] Another measure of dispersion is the reciprocal of the constant r in the equation of the curve. This measure is 2.50 for females as against 2.89 for males, which gives the same ratio of males to females as the interquartile range discussed above.

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NOTES

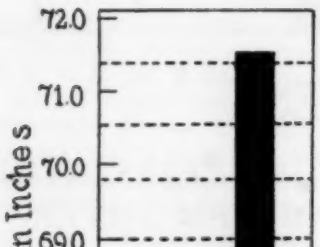
A GRAPHIC METHOD FOR REPRESENTING THE SIGNIFICANCE OF THE DIFFERENCE BETWEEN MEANS[1]

THE bar diagram is frequently used to represent graphically the mean levels of two or more series of observations on the same variate. As it is commonly employed, this type of diagram reveals to the inspector only that the populations represented by the depicted means differ or do not differ with respect to the variable under consideration. Where a statistical analysis has been made, the text must be consulted to learn whether the mean values portrayed differ significantly, or whether the differences shown in the diagram are insignificant and due to the error of random sampling. A modification of the bar diagram is here described which demonstrates by inspection alone the significance of the difference between the populations illustrated.

THE DIFFERENCE BETWEEN THE MEANS OF TWO CLASSES

The standard error of the difference between any two independent quantities is defined as the square root of the sum of the squares of the standard errors of the quantities concerned. Usually, the difference between two values is considered to be significant when it is equal to or greater than two and one-half times its standard error. Such a difference, when representative of large groups, would not be expected to occur by chance alone more often than once in 100 similarly observed samples. The following hypothetical case serves as an example of this principle. The mean height of a large group of second year men in college "A" is 68.2 ± 0.4 inches, while in college "B", the mean height of a similar group is 71.5 ± 0.7 inches. The difference of 3.3 ± 0.8 inches is more than four times its standard error, and the two groups thus differ significantly with respect to this variate. Fig. 1 is a modi-

[1] From the Laboratories of The Rockefeller Institute for Medical Research.



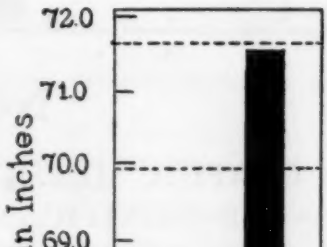


FIG. 1 AND FIG. 2. THE HEIGHT OF SECOND YEAR MEN IN COLLEGES A AND B

fied bar diagram which presents these observations graphically. The horizontal broken lines mark off intervals on the ordinate which are equal to the standard error of the difference between the two means. Slightly more than four such intervals are included between the heights of the two bars, A and B, demonstrating the significance of the difference between them.

Suppose, however, that the two populations had the same means of 68.2 and 71.5 inches but larger standard errors of 1.1 and 1.4 inches respectively. On this basis, the difference of 3.3 inches is identical with that noted in the first example, but its larger standard error of 1.7 inches makes the difference statistically insignificant since it is now less than twice its standard error. These observations are depicted in Fig. 2. It will be noted that the heights of the vertical bars are the same in both figures 1 and 2. In the latter, however, the horizontal broken lines block off larger distances to represent the larger standard error of the difference. Since less than two and one-half such intervals[2] are included between the heights of the two vertical bars, the populations which the latter depict are not significantly different.

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[2] If significance is ascribed to values of $P = 0.05$, then the difference between means should include at least two such intervals instead of two and one-half.

THE DIFFERENCE BETWEEN THE MEANS OF MORE THAN TWO CLASSES

The same method may be employed to depict graphically the significance of the difference between the means of more than two classes. For this purpose the standard error of the mean of any class is calculated by averaging the standard errors of the several means. The standard error of the difference between any two means is equivalent to the square root of twice the square of this average value. The following observations are illustrative. The mean and standard error of the mean of more than 30 observations on the total white blood cell count of each of six individuals follows: "C" = 7100 ± 217; "D" = 6500 ± 190; "E" = 7150 ± 225; "F" = 6180 ± 189; "G" = 6820 ± 232; "H" = 7410 ± 218. The average standard error of the mean is 212. The square root of twice the square of this value is equal to 300 and is an estimate of the standard error of the difference between any two

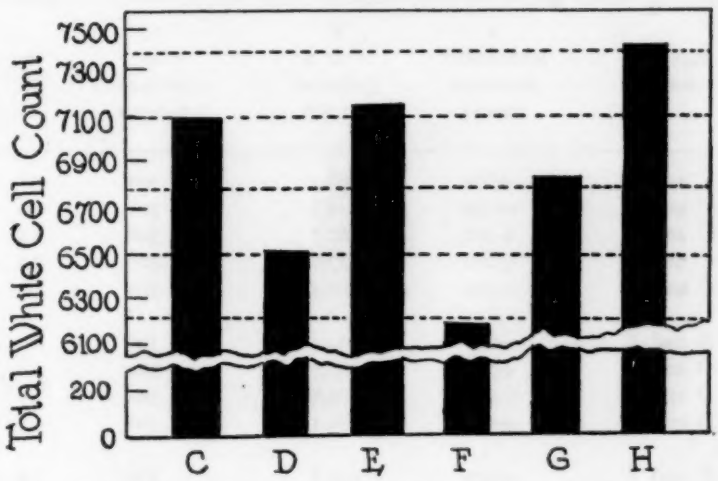

FIG. 3. THE TOTAL WHITE BLOOD CELL COUNT IN SIX INDIVIDUALS

means. In Fig. 3 the dotted lines mark off intervals on the ordinate equal to this value of 300. It is readily seen from the chart that "C" is significantly larger than "F" since the two are separated by a distance of more than three intervals, each equivalent to the standard error of the difference. "C" is not significantly different from "D", "E", "G" or "H" since it is separated from each of these by less than

two and a half intervals. "D" is significantly less than "H", but is not significantly different from any of the others; and "F" is significantly less than "C", "E" and "H".

That the use of the estimated standard error of the mean, obtained as described, to test the significance of the difference between the means of any two classes is a valid procedure, is shown by a comparative analysis based on the actual standard errors observed. In Table 1 the columns headed $\frac{I}{II}$ and $\frac{I}{III}$ indicate the values obtained by dividing

TABLE 1

Comparison of the Significance of the Difference Between Means When Determined by Actual and Estimated Values for the Standard Error of the Mean

CLASSES * COMPARED	I DIFFERENCE BETWEEN MEANS	II σ OF D (ACTUAL VALUE)	III σ OF D (ESTIMATED VALUE)	$\frac{I}{II}$	$\frac{I}{III}$
C and D	+600	288.4	300	2.1	2.0
C and E	— 50	312.5	300	0.2	0.2
C and F	+900	287.7	300	3.2	3.0
C and G	+280	317.6	300	0.9	0.9
C and H	—310	307.5	300	1.0	1.0
D and E	—650	294.4	300	2.2	2.2
D and F	+320	267.9	300	1.2	1.1
D and G	—320	299.8	300	1.1	1.1
D and H	—910	289.1	300	3.1	3.0
E and F	+970	293.8	300	3.3	3.2
E and G	+330	323.2	300	1.0	1.1
E and H	—260	313.3	300	0.9	0.9
F and G	—640	299.0	300	2.1	2.1
F and H	—1220	288.5	300	4.2	4.1

* The mean values for the total white blood cell count of the different classes follow: C = 7100 ± 217; D = 6500 ± 190; E = 7150 ± 225; F = 6180 ± 189; G = 6820 ± 232; H = 7410 ± 218.

the difference between two means by the standard error of the difference; in the first of these columns, the latter was derived from the observed standard errors of the means under comparison and in the second from the estimated standard error. The complete correspondence between the two procedures is evident.

The obvious advantage of the modification described is the additional information which it imparts to the bar diagram.

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